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# Translation

## NUCLEAR POWER PLANT CONSTRUCTION

By

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Moscow STROITEL'STVO ATOMNYKH ELEKTROSTANTSIY in Russian 1979 (signed to press 4 May 79)

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[Excerpts] Chapter 1. Nuclear Power Plant Technology and Equipment

1-1. Nuclear Reactors

Some Information From Nuclear Reactor Physics

Modern nuclear power engineering is based on using the power released on fission of uranium-235 nuclei ($^{235}_{92}U$) existing in nature and also artificially obtained fissionable materials plutonium-239 ($^{239}_{94}Pu$) and uranium-233 ($^{233}_{92}U$). The fission of these nuclei is possible under defined conditions which has required the creation of a set of equipment for realizing the fission reaction--the nuclear reactor.

The thermal power released during fission of nuclei is removed from the nuclear reactor by pumping a liquid or gas coolant through it. This energy can be converted to electric power by obtaining steam designed to turn turbines and also it is used directly in energy-consuming processes, for example, in the chemical or metallurgical industry.

Let us consider the fission reaction in the example of U-235.

The fission of the U-235 nuclei is most probable on absorption of low-energy (thermal) neutrons. On absorption of a thermal neutron $n_T$ by the nucleus, a U-236 nucleus is formed in the excited state:

$$^{235}_{92}U + n_T \rightarrow {}^{236}_{92}U.$$

Fission of the nucleus into two fragments $^{A_1}_{Z_1}F$ and $^{A_2}_{Z_2}F$ with the emission of two or three neutrons n and release of the energy E takes place with approximately 85-percent probability:

$$^{236}_{92}U \rightarrow ^{A_1}_{z_1}F + ^{A_2}_{z_2}F + 2{,}5n + E.$$

The fission fragments are beta-radioactive nuclei of the chemical elements of the middle part of the periodic table. The neutrons formed during fission are broken down into instantaneous (~99 percent), emitted at the time of fission, and delayed (~1 percent), emitted on decay of the fission fragments. The average energy of the delayed neutrons is about $0.8 \cdot 10^{-13}$ joules (0.5 Mev) and the instantaneous, $3.2 \cdot 10^{-13}$ joules (2 Mev). In order to ensure a self-supporting reaction, it is necessary to decrease the energy of the neutrons formed, that is, decelerate them, which is possible on collision of the neutrons with nuclei of light elements.

The self-supporting fission reaction can take place only for defined dimensions (volume) of the reactor, where the leakage of the neutrons is balanced by their formation in the fission process. Such dimensions (volume) are called critical, and the mass of the nuclear fuel which fills the core with critical dimensions is called the critical mass. If the reactor dimensions are less than critical, they are called subcritical, and if greater than critical, supercritical.

In order to decrease the neutron leakage, the reactor core is surrounded by materials which dissipate neutrons well, so-called neutron reflectors. The presence of a reflector increases the number of neutrons in the reactor core participating in the fission process and, consequently, decreases the critical dimensions of the reactor. In addition, the reflector provides for some equalizing of the neutron flux density with respect to the core volume and, consequently, more uniform burnup of the fuel during the operating process. The latter fact is important for the reactors of nuclear power plants, for it permits the time between recharging the fuel accompanied by shutdown of the reactor and interruption of the power supply to be increased.

The total energy released during fission of one uranium atom is $3.2 \cdot 10^{-11}$ joules (200 Mev), and the thermal energy released during fission of 1 gram of uranium is $7.79 \cdot 10^{10}$ joules ($1.86 \cdot 10^{7}$ kcal), which corresponds to burning 2,660 kg of coal in a provisional calculation.

It is necessary to distinguish the electric and thermal power of nuclear power plants. The electric power is determined by the power of the turbogenerators, and the thermal power, by the fuel load and structural design of the reactor.

The thermal power of a reactor $N_p$ in watts with U-235 fuel can be determined from the expression

$$N_p = 3{,}0 \cdot 10^{-11} \Phi \rho \sigma V,$$

where $3.0 \cdot 10^{-11}$ joules (190 Mev) is the thermal power released during fission of one U-235 nucleus under the effect of a thermal neutron; $\Phi$ is the average flux density of the thermal neutrons in the reactor; $\rho$ is the number of nuclei of fissionable material per unit volume of the core; V is the volume of the reactor core; $\sigma$ is the microscopic fission cross section, $cm^2$ (for uranium-235 it can be taken as $585 \cdot 10^{-24}$ $cm^2$).

Natural uranium consists primarily of two isotopes: U-235 and U-238, the content of which in the natural mixture will be approximately 0.7 and 99.3 percent, respectively, with respect to mass.

On irradiation by $^{238}_{92}U$ and $^{232}_{90}Th$ neutrons new fissionable materials $^{233}_{92}U$ and $^{239}_{94}Pu$ can be obtained as a result of the following radioactive chain reactions:

Thorium cycle

$$^{232}_{90}\mathrm{Th} + n \xrightarrow{\gamma} {}^{233}_{90}\mathrm{Th} \xrightarrow{\beta^-} {}^{233}_{91}\mathrm{Pa} \xrightarrow{\beta^-} {}^{233}_{92}\mathrm{U}.$$

Plutonium cycle

$$^{238}_{92}\mathrm{U} + n \xrightarrow{\gamma} {}^{239}_{92}\mathrm{U} \xrightarrow{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow{\beta^-} {}^{239}_{94}\mathrm{Pu}.$$

The final products of these reactions, just as uranium-235, can be used as fuel in nuclear reactors.

The radioactive nuclei formed in the reactor decay with the emission of radiation [69]: alpha-particles with a charge Z = +2 and a mass number A = 4; they consist of two neutrons and two protons, and they are helium nuclei; beta-particles having a unit negative charge equal to an electron charge and its mass; gamma-rays which are electromagnetic vibrations with small wavelength or proton flux.

Basic Elements of Nuclear Reactors

Reactors are classified as a function of purpose, type and physical state of the fuel, the moderator and coolant, and they have their characteristic features. However, the schematic diagrams of all reactors are identical to a high degree. Any nuclear reactor consists of several zones, each having its own purpose. Fission of the fuel nuclei takes place in the core. The heat released during fission is removed by circulation of the coolant through the core.

The number of fissions in the core (and, consequently, the reactor power) is varied by the control rods of the safety and control rod system of the reactor (SUZ) made of materials that absorb neutrons well. The core surrounded by the neutron reflector is placed in the reactor vessel. The reactor vessel is protected by concrete biological shielding which reduces the radiation fluxes to the admissible limit. A thermal protective layer is frequently installed between the vessel and the biological shielding. This thermal layer is designed to take the radiation heat release and prevent radiation damage of the concrete biological shielding.

Nuclear Fuel and Fuel Elements. As has already been stated, uranium-235, uranium-233 and plutonium-239 can be used as the nuclear fuel in the core. The fission of the fuel nuclei can take place under the effect of thermal, intermediate or fast neutrons. Depending on the neutron energy under the effect of which fission of the fuel takes place. the reactors are subdivided into thermal, intermediate and fast neutron reactors.

In thermal neutron reactors [average fission neutron energy <1.6 · $10^{19}$ joules (1 eV)] basically uranium-235 is used as the fuel.

In fast neutron reactors [average fission neutron energy <1.6 · $10^{19}$ joules (1 eV)], uranium-235 is basically used as the fuel.

In fast neutron reactors (average fission neutron energy several hundreds of kilo-electron-volts) basically highly enriched uranium and plutonium-239 are used as the fuel.

The nuclear fuel can be used in solid or liquid form. Accordingly, the reactors are divided, respectively, into heterogeneous and homogeneous reactors. In the homogeneous reactors the nuclear fuel is uniformly mixed with the coolant (and moderator if it is a thermal neutron reactor). In heterogeneous reactors the solid fuel is placed in a jacket which prevents it from interaction with the coolant and localizes the fission fragments.

The fuel placed in the protective jackets is referred to as the fuel elements. Structurally the fuel elements (Figure 1-1) can be made as rod elements (a), plate elements (b), corrugated (c), tubular (d), ball (e), and perforated (f). Rod and tubular fuel elements are most frequently used.

The fuel elements are positioned in the fuel tubes of the reactor by guide assemblies. Sometimes a fuel assembly made up of a cluster of several fuel elements is put in the fuel tubes.

The most widespread fuel for power reactors at the present time is uranium dioxide $UO_2$. It is chemically inert, it is compatible with the majority of structural materials and coolants, it has high thermal resistance (the melting point is about 2,800° C) and high radiation resistance. In the future phase of development of nuclear power engineering uranium and plutonium carbides will obviously become the basic form of fuel in high-temperature reactors. Having a melting point and radiation resistance comparable to uranium dioxide, the carbides have 5 to 10 times higher thermal conductivity and greater density.

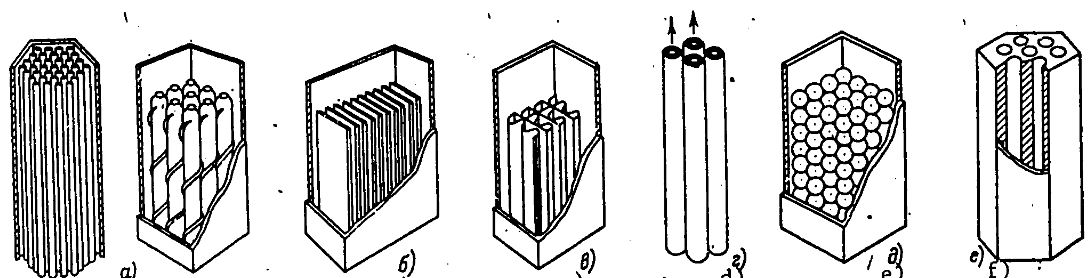


Figure 1-1. Structural diagrams of fuel elements.

Moderator and Reflector. The purpose of the moderator is to lower the energy of the neutrons formed during fission of the fuel nuclei. The best moderators are light materials that do not absorb thermal neutrons. Water $H_2O$, heavy water $D_2O$ and graphite C, more rarely, beryllium Be, have become the most widespread moderators. Heavy water is expensive and is usually used in cases where natural uranium is used as the fuel without enrichment. Ordinary water is used as the moderator for enriched fuel. Graphite, which is a cheap material, is frequently used as the moderator in gas- or water-cooled reactors.

The purpose of the reflector is to increase the number of neutrons in the core and equalize the density distribution of the neutron flux throughout its volume. As the reflectors in the thermal neutron reactors, as a rule, the same materials are used as for the moderators (water, graphite). The core of fast neutron reactors usually is surrounded by a natural uranium reflector. The upper and lower parts of the core fuel elements are filled with natural uranium which forms the upper and lower reflectors. In fast neutron reactors the reflector made of natural uranium is simultaneously a breeding blanket where the plutonium breeding reaction takes place (see the plutonium cycle above).

Coolant. Heat can be removed from the reactor core by two different methods: a coolant is pumped under pressure independently through each fuel tube or through the entire core. In the former case the pressure is taken by the walls of the fuel channels, and in the latter case, by the reactor vessel. Therefore the first type of reactor is called a channel reactor, and the second type, a vessel reactor.

The basic coolant materials are water (ordinary water and heavy water), gases, liquid metals and organic liquids. Water is the most widespread coolant (and moderator) of nuclear power plant reactors.

The basic requirement imposed on water in nuclear power engineering is purity. This arises from the fact that under the effect of water the reactor materials and the materials of the entire circuit are subjected to corrosion and erosion, the products of which cause induced activity of the coolant. In addition, under the effect of radiation decomposition (radiolysis) of the water into hydrogen and oxygen takes place, and hydrogen peroxide is formed. The mixture of these gases is explosive, and the presence of gases has a significant influence on the acceleration of the corrosion processes in the circuit. Therefore during operation of the reactor the water is purified on ion-exchange or high-temperature inorganic filters.

Reactors with water coolant and moderator are called water-cooled, water-moderated power reactors (VVER), and reactors with water coolant and graphite moderator are called water-cooled, graphite-moderated reactors (VGR). They are also frequently called light-water (the coolant is ordinary water), heavy water (the coolant is heavy water), or uranium-graphite reactors (the fuel is uranium, moderator is graphite).

The reactors with water coolant are divided into nonboiling reactors that operate in the water mode, and boiling reactors in which steam is obtained directly in the core and fed to the turbines.

The most widespread among the gas coolants is carbon dioxide combined with graphite moderator. Helium is a prospective coolant for fast neutron reactors and for filling the linings of channel reactors as a result of high thermal conductivity almost 10 times greater than the thermal conductivity of carbon dioxide. However, helium is highly fluid and expensive, which is holding up its application in large power plants. Air can be considered an acceptable coolant. However, it is strongly activated as a result of the presence of argon; therefore it is not used in the high neutron flux zone in large power reactors.

Gases have a small thermal neutron capture cross section, low heat capacity and small heat transfer coefficient, which requires large volumes when they are pumped through the core. Decreasing the volumes of pumped gases leads to an increase in pressure on the reactor vessel, which causes difficulty in building high-pressure vessels. However, the gases can be heated to high temperatures. The upper temperature limit of heating a gas is limited by the maximum admissible temperature of the structural materials of the fuel elements and core. The creation of high-temperature structural materials has made it possible to heat gases in modern reactors to 1,000° C.

Liquid metals are good coolants and are primarily used in fast neutron reactors. This is explained by the fact that they do not slow down the fission neutrons and have good thermophysical properties. The high boiling point of the majority of metals permits high-temperature circuits to be built with low pressure in them. Among the liquid-metal coolants, sodium has become the most widespread. Among the deficiencies of sodium as a coolant which must be considered when designing the cooling systems are increased explosiveness on interaction with water, high induced activity on irradiation by neutrons in the reactor, the necessity for forced heating to 100° C when filling the circuit system and during prolonged shutdowns of the reactor and the necessity for manufacturing sufficiently reliable unique equipment designed to pump a liquid metal.

Safety and Control Rod System (SUZ). The safety and control rod system is designed for starting the reactor, bringing it up to designed power, increasing and maintaining a given power, shutdown and shutdown cooling* of the reactor. In addition, if there is a deviation from the normal operating conditions the safety and control rod system must provide for emergency shutdown of the reactor.

The safety and control rod system of the reactor is one of the principal systems providing for control and safety of the nuclear power plant. It consists of three groups of rods (systems) having defined functions:

the shim rods (KS) are designed to compensate for variations in reactivity when the reactor goes from the cold to the hot state (variation of the thermal coefficient of reactivity) and to compensate for slagging and burnup of the fuel;

the automatic (AR) or manual (RR) control rods are designed to maintain the reactor power and the basic parameters of the coolant on a given level by small variation

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* Shutdown cooling of the reactor is reduction of the temperature and pressure of the coolant to normal when shutting down the reactor, taking place according to defined conditions.

of reactivity. When the effectiveness of the AR rods turns out to be insufficient for these purposes, part of the KS rods are used jointly with them;

the safety rods (AZ) are designed for fast shutdown of the reactor in an emergency.

The reactor power is varied by varying the number of neutrons participating in the fission process in the core. The variation of the neutron balance in the reactor is possible by introducing materials into the core that absorb the neutrons participating in fission well or by increasing the leakage of neutrons out of the core, for example, by shifting the reflector.

Power reactors have SUZ consisting of rods of various shapes: cylindrical, prismatic, cross, hollow and solid, spherical. Materials with large thermal neutron capture cross section (probability) are used as the absorber in the working parts of the SUZ: boron or cadmium in the form of alloys with structural materials or joints included in the jackets. Sometimes provision is made for injection of a liquid absorber (boric acid solution) into the coolant.

Shielding. The shielding of the nuclear reactors of nuclear power plants can perform several functions: reduce the radiation fluxes to the admissible level (biological shielding) and protection of responsible structural elements of the nuclear reactor from extraordinary overheating and radiation damage (heat shielding). The absorption of radiation energy in the vessel material or the concrete shielding leads to the development of high temperatures and temperature gradients and, as a consequence, to the occurrence of significant thermal stresses. In addition, under the effect of radiation over a prolonged period of time the materials change their physical-technical characteristics: steel becomes brittle, and the concrete fillers swell nonuniformly, as a result of which the concrete can lose its strength characteristics which can lead to an emergency. Therefore frequently shields made of heat-resistant radiation-resistant materials that absorb the excess radiation energy and are called heat shields, are installed in front of the highly loaded, responsible structural elements (for example, the vessel or stack of the reactor and also in front of the concrete biological shielding). The reactor vessel can have a heat shield made of cast iron or steel, and protection of the concrete biological shielding is possible by installing a layer of heat-resistant concrete or other heat-resistant materials with desirably high thermal conductivity in front of it.

The biological shielding of the reactor is designed to lower the radiation fluxes to the admissible level. The biological shielding of the reactors of nuclear power plants, as a rule, is made of ordinary heavy concrete (see Chapter 5). The use of concrete arises from its relatively low cost and also good shielding properties against neutron and gamma radiation.

Structural Diagrams of the Reactors of Nuclear Power Plants

Vessel-Type Water-Cooled, Water-Moderated Reactors. The best assimilated power reactors, which have become widespread at nuclear power plants, are the water-cooled, water-moderated reactors which are divided into two types: without boiling the water under pressure VVRD (PWR--pressurized water reactor) and boiling the water VVRK (BWR--boiling water reactor).

The schematic diagram of a vessel-type pressurized water reactor will be considered in the example of the VVER-1000 water-cooled, water-moderated reactor of the Novo-voronezh Nuclear Power Plant (Figure 1-2) [46].

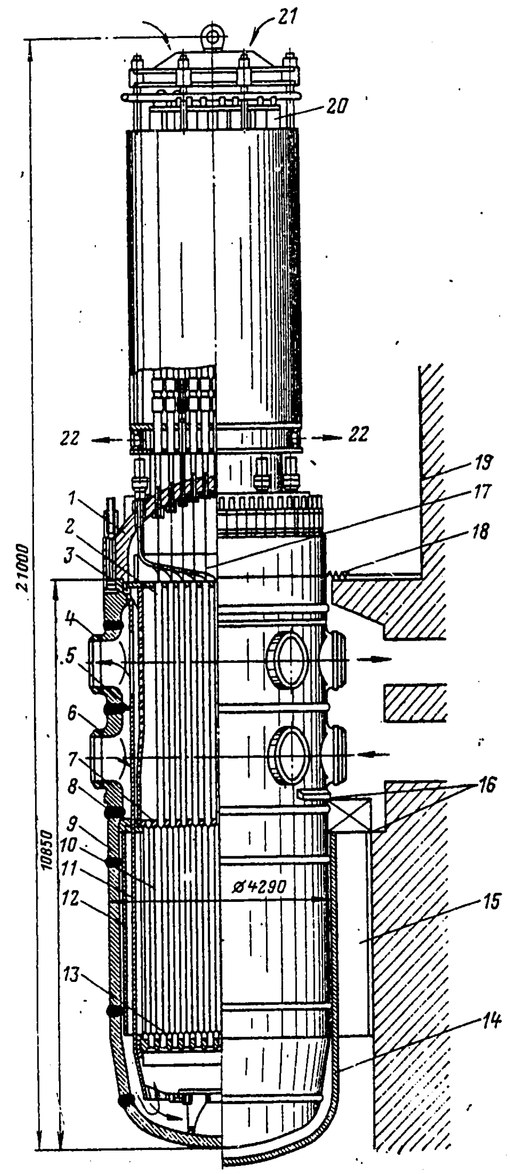


Figure 1-2. VVER-1000 water-cooled, water-moderated reactor. 1--removable cover of the vessel; 2--guide tubes for the servoelements and drives of the safety and control rod system; 3--clamping cylinder; 4--coolant outlet;

Key to Figure 1-2 (continued)

5--separating shell; 6--coolant inlet; 7--clamping plate; 8--restraining belt; 9--reactor vessel; 10--assemblies with fuel elements; 11--core basket; 12--vessel heat shielding; 13--supporting plate (for the assemblies); 14--heat insulation; 15--annular tank with water or "dry" heat shielding; 16--brackets and girder for supporting the vessel; 17--drive rod of the SUZ servoelements; 18--annular sealing and compensating sheet; 19--lining of the facility; 20--hoods for the SUZ servoelement drives; 21--cooling air inlet; 22--cooling air outlet.

The water is fed by circulating pumps through the lower connecting lines, and it drops under the core through the annular clearance between the reactor vessel and the core basket. As the water moves downward it cools the vessel, simultaneously acting as additional shielding of it from the neutrons. Rising and passing through the clearances between the core fuel elements, the water is heated and removed from the reactor through the upper connecting lines. Different auxiliary equipment is located both under and over the core: the reactor power regulating elements, the temperature gauges, and so on. The rod fuel elements assembled in clusters are installed in the basket, fixing the mutual arrangement of the fuel elements and the SUZ rods, the elements of which are fastened inside the vessel. The connecting lines for attaching the main pipelines are located above the lateral cylindrical part of the vessel. The reactor in assembled form, supported by brackets or projections of the vessel on an annular girder, is suspended in a concrete shaft which performs the functions of biological shielding.

The heat shielding of the concrete shaft which simultaneously serves as a moderator for the ionization chambers of the reactor SUZ has up to the present time been made in the form of a tank filled with water located between the vessel and the shaft. A more reliable, cheaper and more convenient shielding is the so-called "dry" shielding which can be made of ordinary or heat-resistant concrete.

The basic parameters of Soviet pressurized water reactors are presented in Table 1-1.

A schematic diagram of a boiling water reactor with internal steam separation is presented in Figure 1-3.

Table 1-1. Basic Parameters of Water-Cooled, Water-Moderated Power Reactors

| Indices | VVER-210 | VVER-365 | VVER-440 | VVER-1000 |
|---|---|---|---|---|
| Power, MW: | | | | |
| Electric | 210 | 365 | 440 | 1,000 |
| Thermal | 760 | 1,320 | 1,375 | 2,940 |
| Efficiency (gross), % | 27.6 | 27.6 | 32.0 | 34.0 |
| Saturated steam pressure in front of the turbine, MPa | 2.9 | 2.9 | 4.5 | 6.0 |
| Pressure in the reactor hull, MPa | 10.0 | 10.5 | 12.5 | 17.0 |
| Number of circulating loops | 6 | 8 | 6 | 4 |

Table 1-1 (continued)

| Indices | VVER-210 | VVER-365 | VVER-440 | VVER-1000 |
|---|---|---|---|---|
| Main circulating pump feed, $m^3/hr$ | 5,600 | 5,600 | 6,500 | 17,000 |
| Power of one turbogenerator, MW | 70 | 73 | 220 | 500 |

The drives and servoelements of the SUZ are usually located underneath the core. The servoelements of the SUZ are analogous to those installed in the PWR (cross rods or tubes with boron carbide placed between the fuel assemblies). As a result of the lower critical loads, the dimensions of the fuel elements in the BWR are larger than in the PWR. The core is located inside the vessel. A separator module which forms a cylindrical cavity between the core and the separators--a steam-water mix chamber--is installed over the core basket. From this chamber the steam-water mix goes to the turboseparators where wet steam is obtained (wetness to 10 percent). The steam is dried by baffle-type separators located in the upper part of the vessel.

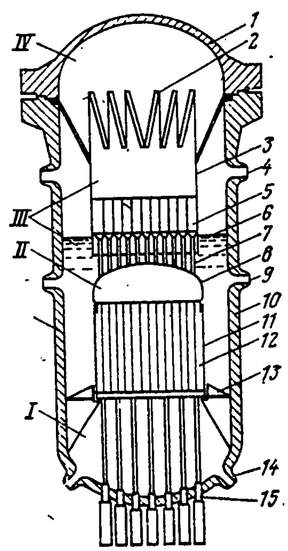


Figure 1-3. Schematic of a BWR reactor. I--pressure chamber; II--steam-water mix chamber; III--separated water and wet steam zone; IV--dry steam cavity; 1--cover; 2--baffle separator; 3--separator module; 4--steam outlet; 5--turboseparator; 6--water level; 7--tubes with steam-water mix; 8--steam-water chamber cover; 9--separated water tap; 10--steel vessel; 11--core basket; 12--fuel assembly; 13--bearing-separating assembly; 14--water feed from the pump; 15--SUZ hydraulic drives.

The BWR reactor, just as the PWR reactor, is recharged after it is shut down and the pressure lowered: the cover is removed and the separator module is taken out with the steam-water chamber cover. The pressure in the BWR reactor vessel caused by the possibilities of intravessel separation and stability of the neutron flux, is, as a rule, about 7.0 MPa.

Reactors With Graphite Moderator. The reactors with graphite moderator are widely used for nuclear power plants as a result of the possibility of using natural, slightly enriched metallic uranium or uranium dioxide as the fuel, obtaining a higher breeding ratio than in the water-cooled, water-moderated type reactors, applying high-temperature gaseous coolants in combination with graphite and also creating systems for recharging without shutting down the reactor.

Graphite-moderated reactors can be both vessel- and channel-type. For vessel-type graphite reactors the coolant used is carbon dioxide, helium and more rarely, other gases (gas-graphite reactors GGR), and for channel-type reactors, ordinary water (water-graphite reactors WGR).

The primary deficiencies of the graphite reactors are high requirements on the purity, structure and radiation resistance of the graphite which operates at high temperatures and significant neutron fluxes. The structural difficulties consist in rigid requirements imposed on the geometric dimensions, verticalness and coaxialness of the channels and also high reliability of an enormous number of independent channel cooling systems.

The WGR reactor is a set of vertical channels inserted in holes in a graphite block lining which constitutes the moderator and reflector. The lining is placed in a sealed vessel filled with inert gas under pressure close to atmospheric. The load from the weight of the core itself is taken by the lower support plate. The top plate, analogous to the bottom plate, rests on a tank filled with water serving as the heat shield for the concrete biological shielding. The header system of coolant pipes from common and group plenums to the heads of the channels is located between the cover of the reactor section and the top plate. The channels run through the space for distribution of the coolant, and they end at the recharging heads. The recharging is done by a special machine installed on the cover of the reactor section. The space under the reactor is taken up with the SUZ drive arrangement.

Table 1-2. Basic Parameters of the WGR Reactors of the Beloyarskaya Nuclear Power Plant

| Indices | First Block | Second Block | On Transcritical Parameters |
|---|---|---|---|
| Power, MW: | | | |
| Thermal | 286 | 530 | 2,220 |
| Electric | 100 | 200 | 1,000 |
| Efficiency (gross), % | 36.3 | 37.8 | 45 |
| Number of circulating loops | 2 | 1 | 1 |
| Power of one turbogenerator, MW | 100 | 100 | 500 |
| Core diameter, m | 7.2 | | 10.2 |
| Core height, m | 6.0 | | 6.0 |
| Type of fuel | $UO_2$ | | UC |
| Weight of graphite lining, t | 810 | | 1,200 |

Table 1-2 (continued)

| Indices | First Block | Second Block | On Transcritical Parameters |
|---|---|---|---|
| Steam parameters ahead of the turbine: | | | |
| Temperature, °C | 500 | | 540 |
| Pressure, MPa | 9.0 | | 24.0 |

Table 1-3. Basic Parameters of RBMK [High-Power Channel-Type Reactors]

| Indices | RBMK-1000 | RBMK-2000 | RBMKP-2000 | RBMKP-2400 |
|---|---|---|---|---|
| Power, MW: | | | | |
| Thermal | 3,200 | 6,280 | 5,620 | 6,500 |
| Electric | 1,000 | 2,000 | 2,000 | 2,400 |
| Efficiency (gross), % | 31.3 | 31.8 | 35.6 | 37.0 |
| Power of one turbogenerator, MW | 500 | 1,000 | 1,000 | 1,200 |
| Core diameter, m | 11.8 | 13.5 | 13.5 | 27 x 7.5* |
| Core height, m | 7.0 | 7.0 | 7.0 | 7.0 |
| Type of fuel | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ |
| Weight of graphite lining, t | 2,000 | 4,000 | 4,000 | -- |

* Length x width.

Table 1-4. Basic Parameters of Fast Neutron [BN] Reactors

| Indices | BN-350 | BN-600 | BN-1000 | BN-1500 |
|---|---|---|---|---|
| Power, MW: | | | | |
| Thermal | 1,000 | 1,470 | 2,250 | 3,500 |
| Electric | 150 | 600 | 1,000 | 1,500 |
| Freshwater output, $m^3$/day | 120,000 | -- | -- | -- |
| Efficiency (gross), % | 35 | 43 | 43 | 43 |
| Number of circuits | 3 | 3 | 3 | 3 |
| Coolant | | Sodium | | |
| Number of cooling loops | 6 | 3 | -- | -- |
| Power of one turbogenerator, MW | 50 | 200 | 500 | 500 |
| Steam parameters ahead of the turbine: | | | | |
| Temperature, °C | 440 | 505 | 500-510 | 500-510 |
| Pressure, MPa | 5 | 14 | 13.0-16.0 | 13.0-16.0 |

The weight of the reactor is transferred to the concrete using welded metal structures which are simultaneously used for biological shielding and (together with the vessel) form a field cavity filled with a mixture of helium and nitrogen--the reactor space in which the graphite lining is placed.

In the WGR reactors of the Beloyarsk Nuclear Power Plant (Table 1-2), superheated steam is obtained directly in the hot channels of the core. For this purpose there are two types of channels--evaporation and steam superheating channels.

In the evaporation channels the water is converted to a steam-water mix which is fed to the separator. The steam, separated from the water in the separator, goes to the superheated steam channels and is removed from the reactor at 480° C and 9 MPa (nuclear steam superheating). On passage through the core the steam is activated; therefore the turbine condensers, the live steam lines and other auxiliary equipment at such nuclear power plants must be surrounded by biological shielding.

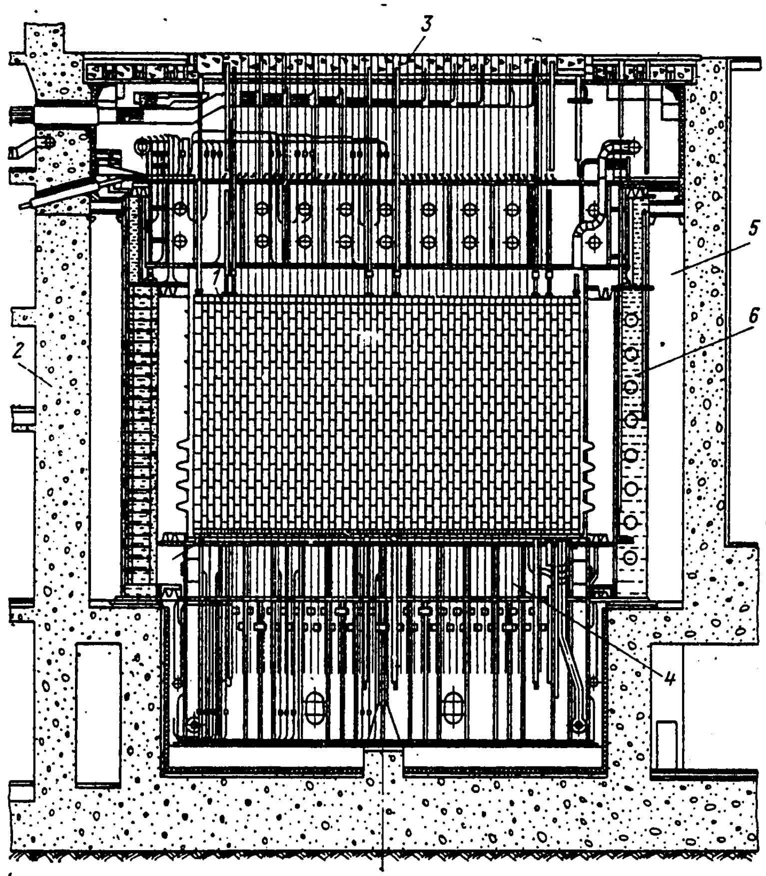


Figure 1-4. Section of the nuclear power plant building with the RBMK-1000 reactor in the vicinity of the reactor pit. 1--steel blocks; 2--ordinary concrete; 3--iron-barium-serpentinite concrete stone; 4--serpentinite; 5--sand; 6--water.

The further development of reactors of this type has proceeded along the path of simplifying the structural design of the channels (one-way movement of the coolant), replacement of stainless steel, which has a significant neutron capture cross section, by zirconium (improvement of the neutron balance), the use of the well-assimilated dioxide fuel in the form of clusters in a zirconium jacket, an increase in the unit power and also provision for almost continuous recharging. These

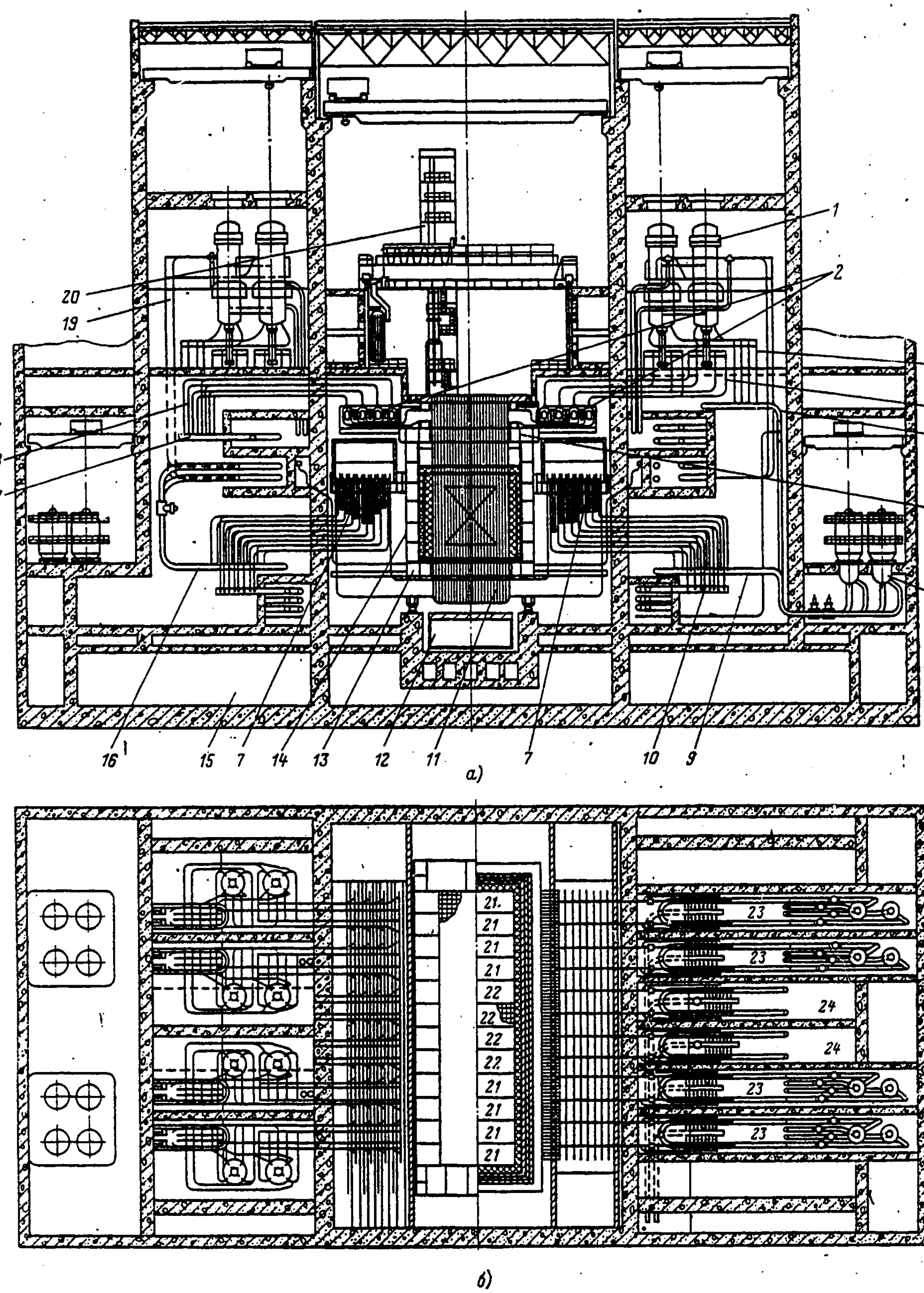


Figure 1-5. Nuclear power plant building with RBMKP-2400 reactor.

Key to Figure 1-5:

a--section; b--plan; 1--steam separator; 2--collecting group plenums; 3--top water pipes; 4--steam-water mix pipes; 5--intake plenum; 6--top block; 7--distribution group plenums; 8--main circulating pump; 9--delivery plenum; 10--feedwater plenum; 11--reactor core; 12--lower maintenance machine; 13--bottom block; 14--side block; 15--bubbler basin; 16--saturated steam plenum; 17--superheated steam plenum; 18--superheated steam lines; 19--saturated steam lines; 20--loader; 21--evaporation section; 22--superheating section; 23--evaporation loop box; 24--superheating loop box.

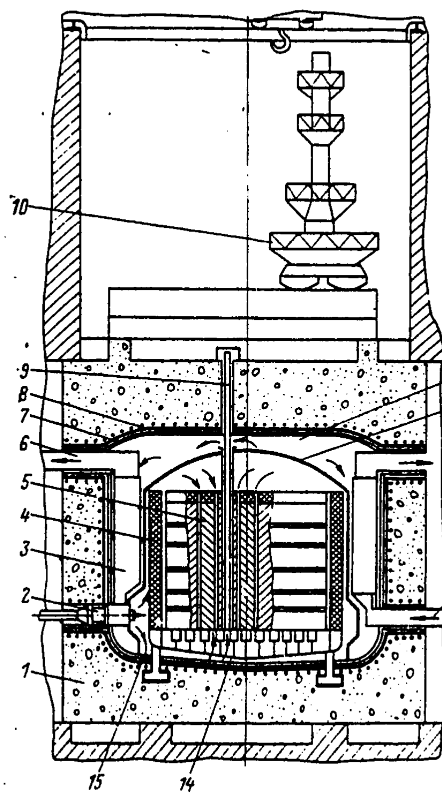


Figure 1-6. General view of a gas-graphite reactor in a reinforced-concrete vessel. 1--reactor vessel made of prestressed reinforced concrete; 2--gas blower; 3--steam generator; 4--heat shield; 5--core lining; 6--steam outlet; 7--heat insulation of the vessel; 8--internal sealing lining of the vessel; 9--channel; 10--fuel recharging machine; 11--hot gas chamber; 12--internal vessel forming a cold chamber for feeding part of the gas to cool the moderator; 13--feedwater supply; 14--structural supports; 15--feed of part of the gas from the gas blower to the core.

reactors, called RBMK (high-power, channel-type reactors) (see Figure 1-4) are installed at many nuclear power plants in the USSR (Leningrad, Kursk, Smolensk, Chernobyl'skaya, and so on).

As a result of improving the RBMK-type reactors, designs have been developed for various powers of these reactors: RBMK-1000, RBMK-2000, RBMKP-2000, RBMKP-2400. In the last two provision has been made for superheating of steam. The basic parameters of the RBMK reactors are presented in Table 1-3.

The effort to organize industrial methods of manufacture and installation of reactors and also to vary their unit power depending on the power engineering requirements has led to the development of a design for a sectional-modular RBMKP-2400 uranium-graphite reactor (Figure 1-5). This reactor is assembled from standard central and end sections. In plan view the core is a rectangle, the length of which is determined by the number of central sections. The reactor sections are portable, autonomous and include the required equipment, monitoring and control elements.

The gas-graphite vessel-type reactor GGR for nuclear power plants has become the most widespread in England and France. An example of the structural design of an improved gas reactor (UGR) in a vessel made of prestressed reinforced concrete is presented in Figure 1-6.

The future of nuclear power engineering belongs to the fast neutron reactor (BN). Along with obtaining power, breeder reactions are realized in such reactors (see above). Gases or liquid metals, primarily sodium, are used as the coolant in fast neutron reactors.

For the BN-600 power reactor (Figure 1-7) built at the Beloyarskaya Nuclear Power Plant, an integral (tank) arrangement of the radioactive process equipment was used: core, pumps and intermediate heat exchangers are located in a single sealed tank. The high coolant temperatures at the exit from the core increase the efficiency of the nuclear power plant and permit the use of steam with the parameters adopted at modern thermal electric power plants (Table 1-4).

## 1-2. Types of Nuclear Power Plants. Primary Process Equipment

### Flow Diagrams of Nuclear Power Plants

The consumption charts for electric power generated by all types of electric power plants are nonuniform and depend on the time of day (there is a sharp decrease in electric power consumption at night and an increase during the day with a trough at the lunch break), the day of the week (a decrease in electric power consumption on Saturday, Sunday and holidays) and time of year (a decrease in electric power consumption in the summer as compared to the winter).

In order to increase the maneuverability and reliability of the electric power supply and also to improve the quality of electric power supply, the power plants have been joined into a common power system which offers the possibility of decreasing the power reserve at each electric power plant as a result of noncoincidence in time of the peak loads in different areas, and it facilitates the passage through the nighttime load dip.

Nuclear power plants, just as thermal electric power plants, can operate in a common power system joined by electric networks, and they can operate in isolation, covering the needs of a defined area, for example, in inaccessible parts of the Soviet Union or in areas where there are no nearby organic fuel deposits.

In order to cover the peak loads it is efficient to create "peak" power plants which operate for a relatively short time (1 or 2 hours a day or less). The basic requirements imposed on these plants is maximum reduction of the cost of equipment. The cost of the electric power (the efficiency of the device) does not have decisive significance in this case.

The majority of thermal plants are equipped as base plants, that is, for prolonged operation in the rated mode. Considering the significant capital consumption of nuclear power plants, at the present time they are basically built also as base plants.

Just as the thermal electric power plants, the nuclear power plants are divided into condensation and heat-electric generating plants. At the condensation nuclear power plants, after the turbine (which is also called a condensing turbine) the steam goes to a heat exchanger-condenser in which the residual heat is transferred to cold water from the sea, a river, a cooling pond or cooling tower.

In the heat and electric nuclear power plants the heat removed from the turbines (heat and electric generating turbines) can be sent to the users for subsequent use in the form of hot water or steam (for enterprises, heating buildings, and so on). These plants are called nuclear heat and electric power plants (ATETs).

In the modern nuclear power plants the working substance (the substance which performs work converting thermal power to mechanical) is steam.

There are several flow diagrams for nuclear power plants (Figure 1-8), but in any of them it is necessary to construct biological shielding around the equipment which is a source of ionizing radiation. This shielding can be provisionally divided into primary shielding--the shielding for the reactor itself--and secondary shielding--the shielding for the pipelines and other equipment, access to which is possible after the reactor is shut down.

In the single-circuit layout of a nuclear power plant (Figure 1-8a) the coolant and the working substance coincide. The steam formed in the core is separated and fed to the turbine. The spent steam is condensed and again fed to the reactor. This system is characteristic of boiling reactors in which all of the equipment, including the turbine, operates under radiation conditions,* which is one of the deficiencies of the system. However, a significant advantage of such nuclear power plants is a smaller amount of heat engineering equipment and, consequently, a decrease in heat losses and an increase in efficiency.

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* Here and hereafter the term "radiation conditions" means the presence of excessive ionizing radiation and radioactive isotopes in the work areas.

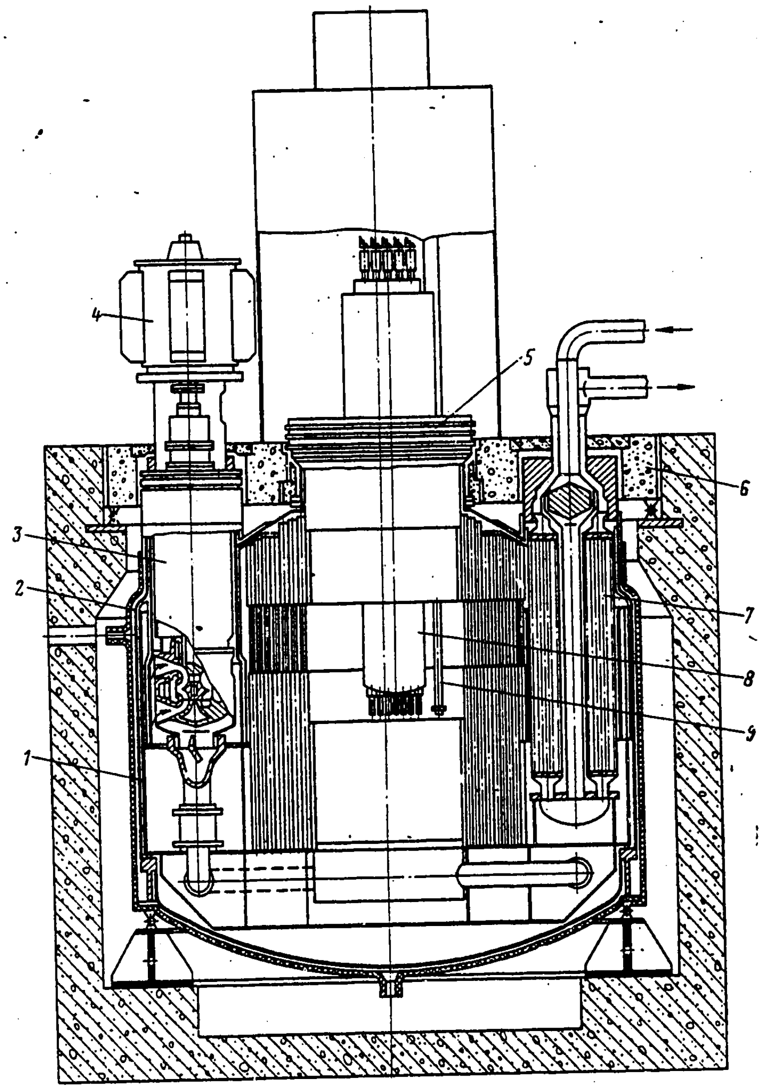


Figure 1-7. BN-600 fast neutron reactor. 1--supporting structure; 2--reactor tank; 3--pump; 4--pump electric motor; 5--rotating plug; 6--top stationary sealing; 7--heat exchanger; 8--central SUZ assembly; 9--charging device.

The two-circuit nuclear power plants have become most widespread, in which the coolant and working substance circuits are separate (Figure 1-8b). The radioactive coolant circuit is called the primary circuit, and the nonradioactive working substance circuit, the secondary circuit. The coolant, which is heated in the core, is fed to a steam generator, it transfers heat to the water of the secondary circuit which converts it to steam, and it is returned to the reactor by a circulating pump. The steam formed in the steam generator is fed to a turbine, then it is condensed, and the condensate is returned to the steam generator. The absence of radioactivity in the secondary circuit simplifies operation of the plant.

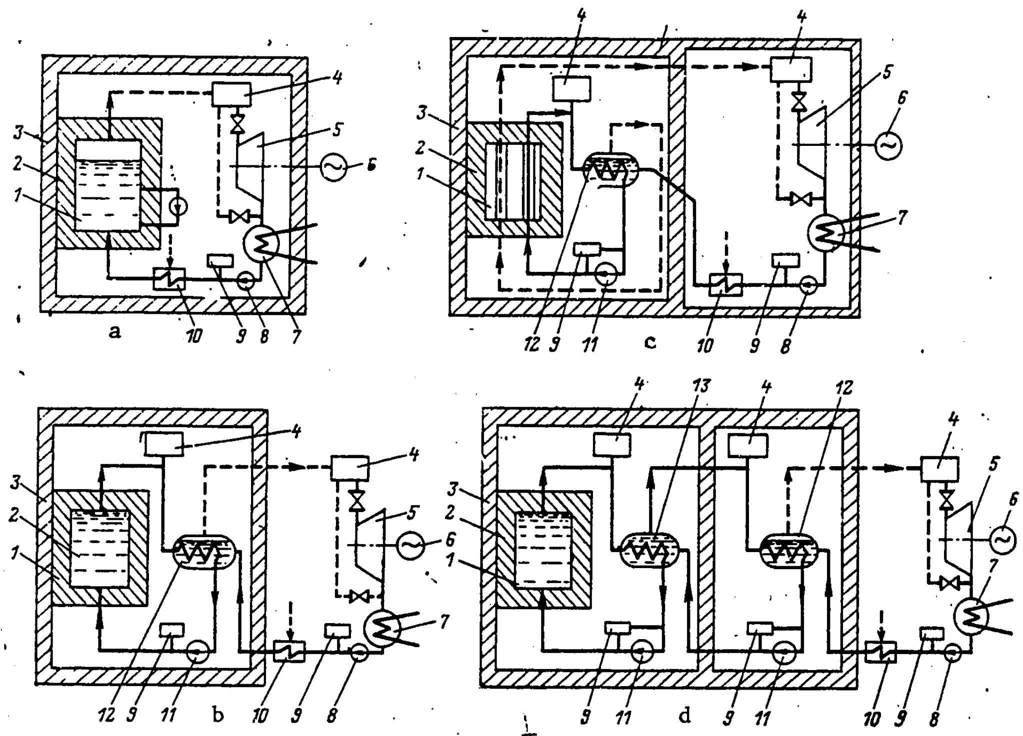


Figure 1-8. Flow diagrams of nuclear power plants. a--single-circuit; b--double-circuit; c--incompletely double-circuit; d--triple-circuit; 1--reactor; 2--primary biological shielding; 3--secondary biological shielding; 4--pressure regulator in the circuit; 5--turbine; 6--electric power generator; 7--condenser or gas cooler; 8--pump or compressor; 9--coolant or working substance makeup tank; 10--recovery-heat heater; 11--circulating pump; 12--steam generator--13--intermediate heat exchanger.

In the two-circuit system the nuclear power plants operate with vessel-type water-cooled, water-moderated reactors, for example, the Novovoronezh Nuclear Power Plant.

Water, gas or organic coolants can be used as the coolants in the primary circuit of the two-circuit system. Quite high pressure should be maintained here to avoid boiling of the coolant and in connection with the necessity for having a sufficient temperature gradient in the steam generator between the coolant and the water of the secondary circuit.

In order to increase the efficiency of nuclear power plants it is desirable to feed superheated steam to the turbines. Accordingly, the incompletely two-circuit heat output system has appeared (see Figure 1-8c). The water heated in the reactor is fed to a steam generator and is returned to the reactor. The saturated steam formed in the steam generator is fed to the reactor for superheating, and therefore it is simultaneously a coolant and a working substance. Then the superheated steam is fed to the turbine. This system is called a nuclear superheating system. The channel-type water-cooled, graphite-moderated reactors of the Beloyarsk Nuclear Power Plant operate by this system.

Sodium which reacts violently with water and steam is used as the coolant in fast neutron reactors. Accordingly, an additional intermediate circuit has been built which excludes the possibility of failure of the primary radioactive circuit even in case of an emergency. These nuclear power plants are called three-circuit plants (Figure 1-8d). Sodium circulates in the primary circuit. It passes through an intermediate heat exchanger and releases heat to the sodium of the secondary circuit. The sodium of the secondary circuit, passing through the steam generator, gives off heat to the water of the third circuit; the system does not differ from the two-circuit system after that. The presence of a second, intermediate circuit leads to an increase in capital expenditures, but it ensures safe operation of the reactor. The three-circuit output system has been used in the BN-350 reactor at the nuclear power plant built at Shevchenko.

In recent years significant development has taken place in the design and construction of floating (on barges) nuclear power plants (PAES). The primary advantages of the PAES by comparison with the ordinary nuclear power plants are the following: the possibility of selecting the base station of the PAES near the electric load center, independent of seismic conditions, unlimited cold water reserves and the possibility of using a direct-flow water supply system (see below), the use of a standard design for a series of power plants not requiring adaptation to local conditions and, accordingly, reduction of the design times, higher quality of construction and installation work, and future reduction in construction cost. These power plants are built on the basis of ordinary pressurized water reactors.

In recent years a great deal of attention has begun to be given to the possibility of using nuclear reactors to build heat supply nuclear plants (AST). This is explained by the creation of reliable and economical small and medium power reactors. As a result of the absence of heat losses in the exhaust gases, the thermal efficiency of the AST is higher than that of industrial, district and, especially, block and local boiler rooms. In addition, the use of AST leads to reduced air pollution in cities, for the nuclear sources are the most "humane" of the known energy sources.

All of the heat engineering equipment of nuclear power plants has been subdivided with respect to process stages into reactor, steam generating, steam turbine and condensation units and the condensation-makeup cycle. The interrelation among these elements forms the heating system of the plant [37, 50].

The purpose of the basic process equipment can be demonstrated in the example of a simplified heat diagram of a two-circuit nuclear power plant with water-cooled, water-moderated reactor (Figure 1-9).

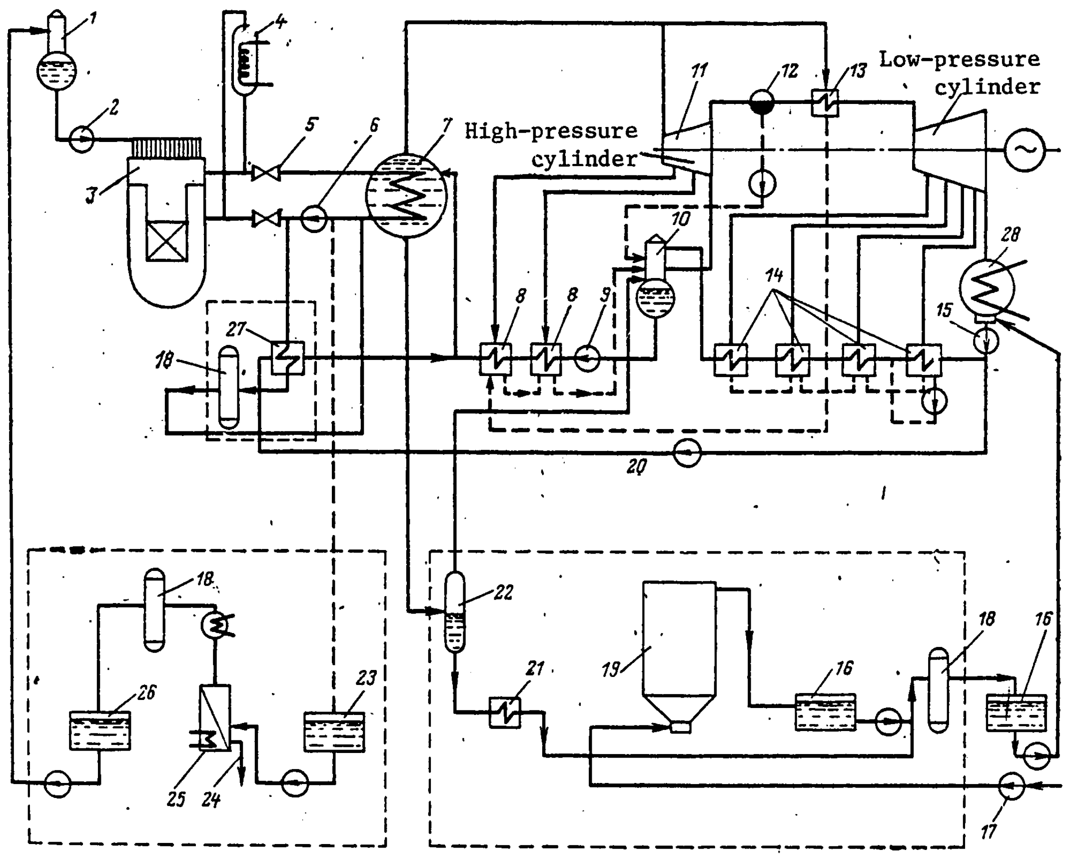


Figure 1-9. Heat diagram of a two-circuit nuclear power plant.

Heating of the coolant (water) takes place in the reactor 3. The water goes through the lines of the primary circuit equipped with a slide valve 5 to the steam generator 7. In the steam generator heat transfer takes place from the coolant to the working substance of the secondary circuit, steam is generated, which is fed to the high-pressure cylinder of the turbogenerator 11. The coolant from the steam generator is fed to the reactor by the main circulating pumps 6 through the lines. Thus, the purpose of the primary circuit is transfer of the heat released in the reactor to the working substance. The expansion tank 4 is designed to compensate for the thermal expansion of the coolant during heating up and cooling down of the reactor.

In order to keep the water in the primary circuit pure, on the given level continuous removal of the impurities formed as a result of corrosion of the structural materials is required. The impurities are removed by tapping (blowdown) of part of the water, purification of it and subsequent return of it to the circuit. The blow-off water consumption is determined by the normative content of impurities in the coolant, and it can vary within quite broad limits for various types of nuclear power plants (for example, it is 0.5 ton/hr at the Beloyarskaya Nuclear Power Plant and 25 tons/hr at Novovoronezhskaya).

In the investigated system the blowdown water is taken from the line located between the main circulating pump 6 and the slide valve. The blowdown water passes through the blowdown cooler 27 fed by the pump 20, the filter group 18 (ion exchange filters) and returns to the circuit.

Another method of purifying the primary circuit water which is used along with continuous blowdown is special water purification. The primary circuit water (or leaks, drainage water, and so on) is collected in the active condensate tank 23, and it is pumped to the evaporation units 25 where as a result of tapping hot steam from the turbine, the condensate evaporates which then is sent to the filter group 18 and collected in the pure condensate tank 26. For the greatest purification of the condensate, the activity reaches $10^{-8}$ curies/kg and it is taken as standardized for the condensate of a single-circuit nuclear power plant. The condensate vapor goes through a special wastewater disposal system to the liquid waste storage 24. The purified condensate is pumped to the makeup deaerator 1 for degassing and is returned by the makeup pump 2 to the reactor 3.

The steam formed in the steam generator 7 completes work in the high-pressure cylinder of the turbounit 11 and is humidified. In order to decrease the corrosion of the low-pressure cylinder vanes of the turbine, which depends on the moisture, after the high-pressure cylinder the steam is passed through the separator 12 where the moisture is separated out, the heater 13 and then to the low-pressure cylinder. The separator condensate goes to the deaerator 10 for degassing. The steam is superheated in the steam superheater 13 by tapping off live steam from the steam generator 7.

After the turbine the spent steam is condensed in the condenser 28 and it is pumped by the condensate pump 15 through the recovery-heat low-pressure heater (PND) 14 to the deaerator 10 for degassing. The condensation of the spent steam in the condenser 28 is realized by the service water from the sea, a river, cooling pond or cooling tower.

The purpose of the recovery-heat heating of the feedwater is to increase the efficiency of the nuclear power plant as a result of removal of heat from the steam in the turbine and transfer of it to the feedwater for heating. The condensate formed here is returned to the feed cycle. Theoretically, the more steam tapped from the turbine and the more feedwater heaters, the higher the efficiency of the cycle. However, increasing the temperature of the feedwater is permitted to a defined limit where the increase in efficiency does not compensate for the additional expenditures on equipment (the recovery-heat heaters, steam generator).

The purpose of the deaerator 10 is to purify all of the condensate formed to remove the gases dissolved in it as a result of boiling during heating by the steam from the high-pressure cylinder. The degassed condensate is collected in the deaerator tank and is pumped by the feed pump 9 through the recovery-heat high-pressure heater (PVD) 8 to the steam generator 7. The feedwater is heated in the PVD by steam from the turbine high-pressure cylinder. The condensate formed is sent to the deaerator 10 for degassing.

The purification (blowdown) of the secondary-circuit water is accomplished by trapping the water from the steam generator with subsequent feed to the expansion tank 22, the cooler 21 and the filter group 18. The purified feedwater is collected in the tank 16 and pumped to the turbine condenser. The feedwater makeup for the second circuit is realized by feeding the "raw" water by the pump 17 to the clarifier 19, collection of the clarified water in the tank 16, from which it is sent through the filter group 18 to the pure condensate tank 16.

The described heat diagram of the nuclear power plant with water-cooled, water-moderated reactors in metal vessels, which is the system used in the third power unit of the Novovoronezhskaya Nuclear Power Plant, has become most widespread, and it is used at a number of Soviet and foreign nuclear power plants. The Kola and the Armenian nuclear power plants and also the Nord Nuclear Power Plant (GDR), the Kozloduy (People's Republic of Bulgaria), Paksh (Hungarian People's Republic), Haddam Neck (United States), Stade (FRG), and others operate by this system.

In the third stage of the Novovoronezh Nuclear Power Plant, the VVER-440 reactor was installed which has six circulating loops (one loop is presented in Figure 1-8). Each loop has a steam generator 7 and circulating pump 6. The lines and the slide valves are made from austenitic steel. The water pressure in the circuit is 12.3 MPa, and the temperature at the exit from the reactor is 300° C. Two of the type K-220-44 turbines (with one high-pressure cylinder and two low-pressure cylinders) operating on saturated steam are provided for each reactor.

Let us consider other heat diagrams of nuclear power plants having characteristic features.

The heat diagram with a channel-type boiling reactor is used at the Leningrad Nuclear Power Plant (see Figure 1-10). Similar systems are used for the Kursk, Smolensk, Chernobyl'skaya and other Soviet nuclear power plants of this type.

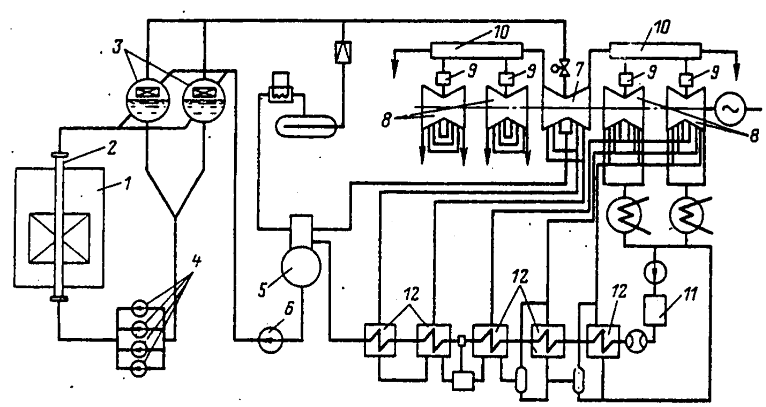


Figure 1-10. Heat diagram with channel-type boiling reactor (Leningrad Nuclear Power Plant).

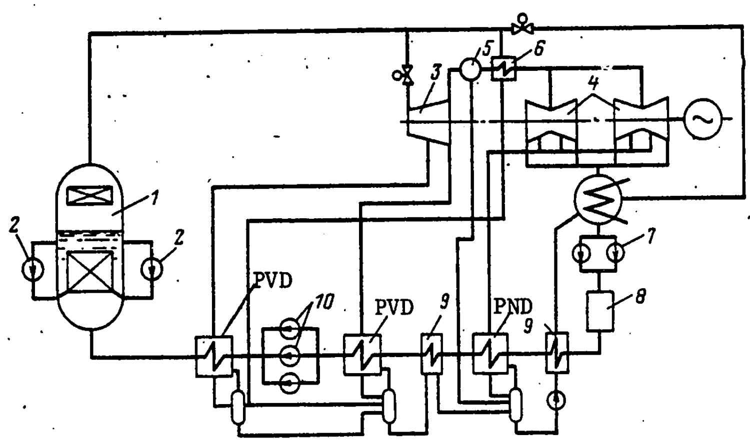


Figure 1-11. Heat diagram with vessel-type boiling reactor (Muleberg Nuclear Power Plant). 1--reactor; 2--circulating pump; 3--high-pressure cylinder of a steam turbine; 4--low-pressure cylinder with steam turbine; 5--separator; 6--steam superheater; 7--condensate pump; 8--condensate purification; 9--condensate cooler; 10--feed pump; PVD = recovery-heat heater; PND = low-pressure recovery-heat heater.

The power unit of these nuclear power plants consists of one RBMK-1000 reactor and two K-500-65 turbogenerators with a power of 500 MW each. Each reactor has two circulating loops (one loop is shown in Figure 1-9) consisting of four circulating pumps with a feed of 7,000 $m^3$/hr, two external evaporator-separators 2.3 meters in diameter, 30 meters long and 22 distribution group plenums 300 mm in diameter feeding the reactor channels.

The water in the channels 2 of the reactor 1 is heated to the boiling point, it is collected in the plenums and sent to the separators 3. After separation, the water is pumped by the circulating pumps 4 to the reactor, and the saturated steam under a pressure of about 6.5 MPa with 0.1-0.2-percent moisture is fed to a five-cylinder turbine with one high-pressure cylinder 7 and four low-pressure cylinders 8. Separators 10 and intermediate steam superheaters 9 are installed between the high-pressure cylinder and the low-pressure cylinder. A characteristic feature of the nuclear power plant is 100-percent purification of the condensate 11. The purified condensate is returned by means of the feed pump 6 through the system of recovery-heat heaters (high-pressure heater and low-pressure heater) 12 and the deaerator 5 to the separator 3.

The heat diagram with a vessel-type boiling reactor and internal steam separation (Figure 1-11) is used at the Muleberg Nuclear Power Plant (Switzerland). The power unit of this nuclear power plant consists of a reactor with forced circulation of the coolant and two turbogenerators of 163 MW each with one high-pressure cylinder and two low-pressure cylinders. The nuclear power plants of Oyster Creek (United States), Dresden-2 (United States), Fukusima-1 (Japan), Dodevaard (Netherlands), Tarapur-1 (India), and so on operate by analogous flow diagrams.

The systems with boiling vessel reactors, internal separation and natural circulation of the coolant have become widespread. They are used at the nuclear power plants at Vallesitos (United States), Humbolt Bay (United States), Big Rock Point (United States), and elsewhere. The heat diagrams of these nuclear power plants are similar to the diagram presented in Figure 1-11. The difference consists in absence of circulating pumps.

The heat diagrams of nuclear power plants with gas-cooled reactors are divided with respect to thermodynamic cycle into steam-turbine and gas-turbine systems and with respect to number of circuits, into two-circuit and one-circuit, respectively.

The most widespread are the steam-turbine cycles with gas-graphite and improved gas reactors (UGR). However, the most prospective are the high-temperature gas reactors (VTGR) [10], which, as a result of high coolant temperatures (850° C and higher), can also be used for process engineering purposes: in the chemical industry, to obtain artificial methane from coal; in the metallurgical industry they are used to recover iron from ore.

The heat system with VTGR at the Fort Saint Vrain Nuclear Power Plant (United States) is presented in Figure 1-12. The electric power capacity of the nuclear power plant is 330 MW. The reactor is cooled by helium under a pressure of 4.8 MPa, the temperature of which at the entrance reaches 404° C and at the exit, 776° C. The layout of the reactor equipment is integral. In the two circulating loops there are two compressors 1 and six direct-flow steam generators 2. The steam under a pressure of 16.6 MPa with a temperature of 538° C is fed to the high-pressure cylinder 6, then to the compressor 1, it is again heated to a temperature of 538° C in the steam generator, and it is fed under a pressure of 4.1 MPa to the medium-pressure cylinder 7 of the turbounit. The recovery-heat heating consists of three low-pressure heaters, a deaerator and two high-pressure heaters.

The heat systems of nuclear power plants with fast neutron reactors are made in the loop or tank version. Each of these versions has its advantages and disadvantages, and at the present time there are no grounds for rejecting either of them.

A distinguishing feature of nuclear power plants with such reactors is the presence of an intermediate circuit between the liquid-metal coolant and the steam-water channel. As an example of a heat system with fast neutron reactor and liquid-metal coolant, the third power unit of the Beloyarsk Nuclear Power Plant is presented (Figure 1-13). The BN-600 reactor with basic process equipment of the primary circuit is placed in a tank 1. Three pumps 4 and six heat exchangers 3 form three loops. One power unit includes the reactor and three K-200-130 turbines operating on steam at a pressure of 12.7 MPa and at a temperature of 535° C.

Main Circulating Pumps (GTsN)

The basic requirements imposed on the main circulating pumps connected with their specific operating conditions (radioactive coolant transfer) is reliability and seal [78].

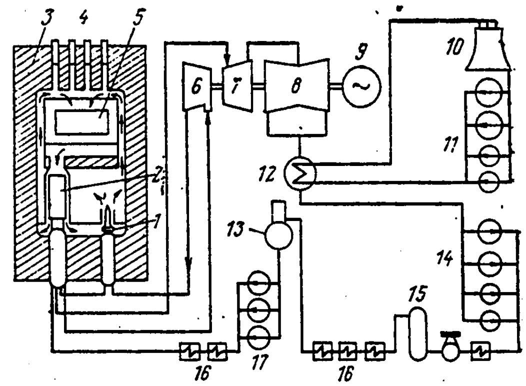


Figure 1-12. Heat diagram with high-temperature gas reactor (Fort Saint Vrain Nuclear Power Plant). 1--compressor for helium; 2--steam generator; 3--vessel made of prestressed reinforced concrete; 4--holes for recharging fuel; 5--core; 6--high-pressure cylinder (TsVD); 7--medium-pressure cylinder (TsSD); 8--low-pressure cylinder (TsND); 9--generator; 10--cooling tower; 11--circulating pumps; 12--condenser; 13--heater-deaerator; 14--condensate pumps; 15--demineralizer; 16--feedwater heaters; 17--feed pumps.

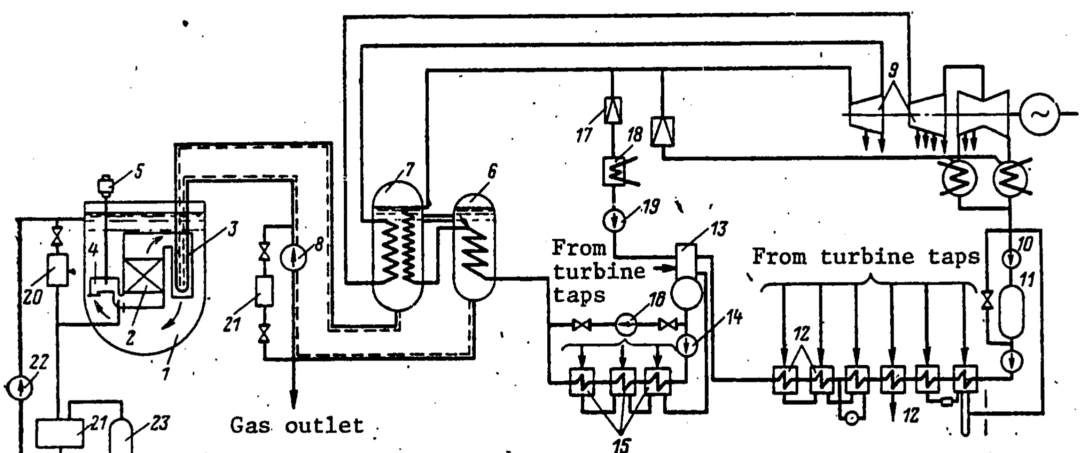


Figure 1-13. Heat diagram with fast neutron reactor (third power unit of the Beloyarsk Nuclear Power Plant with BN-600 reactor). 1--reactor tank; 2--reactor core; 3--intermediate heat exchanger; 4--circulating pump; 5--circulating pump electric motor; 6--evaporator; 7--steam superheater; 8--secondary-circuit circulating pump; 9--turbine; 10--condensate pump; 11--condensate purification; 12--low-pressure heaters; 13--deaerator; 14--pump; 15--high-pressure heaters; 16--shutdown cooling pump; 17--reduction-cooling unit (ROU); 18--cooler; 19--condensate pump; 20--trap filters; 21--sodium drainage tanks; 22--sodium transfer pumps; 23--tanks for storing argon.

The structural execution and materials for making the pumps must correspond to high requirements in connection with the high corrosion activity and radioactivity of the transferred water.

The main electric circulating pump TsEN-310 is series manufactured for nuclear power plants with VVER-440 water-cooled, water-moderated reactors (third and fourth power units of the Novovoronezhskaya Nuclear Power Plant, Kola and Armenian nuclear power plants). The drive is an asynchronous electric motor for operation on three-phase, AC, 50-Hz current and at a voltage of 6,000 volts. The significant heat releases are picked up by an autonomous water- and air-cooling circuit. It is designed to feed 6,500 $m^3$/hr. The weight of the pump with the frame and all of the accessory products, but without biological shielding is 48 tons (the pump itself is 41 tons). The overall dimensions of the pump are as follows: height from the stand 6.73 meters, in plan view 3.83 x 3 meters.

The TsEN-195 electric vane circulating pump (Figure 1-14) with mechanical seal of the shaft and monitored leaks is made for use in a loop of the VVER-1000 water-cooled, water-moderated reactors which will become widespread in nuclear power engineering in the USSR in the next decade. The TsEN-195 pump installed on the fifth power unit of the Novovoronezh Nuclear Power Plant is designed to feed 19,000 $m^3$/hr; its overall dimensions are as follows: height (without rotating crank on the suction) 9.7 meters, in plan view 2.9 x 2.8 meters; assembled weight 100 tons.

The conversion from high-delivery pumps for nuclear power plants with VVER-1000 reactors made it possible to reduce the number of circulating loops servicing the reactor to four (by comparison with six loops on the nuclear power plants with the VVER-440 reactor).

The TsVN-7 circulating pump with mechanical seal of the shaft and controlled leaks is made for use in the circulating loops of nuclear power plants using the RBMK-1000 boiling reactors. It is designed to deliver 6,850 $m^3$/hr. Overall dimensions: height 10.22 meters, height from top to cover 7.69 meters, in plan view 2.7 x 3.23 meters. The total weight 127 tons, electric motor weight 28 tons.

In the case of the pumps with liquid-metal coolant a gas cushion is created over the sodium level which when the gas leaks completely excludes leakage of the coolant. Structurally the liquid-metal pumps of the primary and intermediate circuits of the nuclear power plant at Shevchenko with the BN-350 reactor are made identically, but the primary circuit pump has biological shielding [50, 85]. These pumps are centrifugal, cradle-mounted with electric motor and mechanical seal. The overall dimensions of the BN-350 reactor pump are as follows: height 9.87 meters, height from the level of the biological shielding to the top of the pump 7.4 meters, diameter of the support plate in plan view 4.6 meters.

Increasing the unit power of the nuclear power plant and, consequently, the pumps, and also the gas-blowing of the nuclear power plants with gas reactors leads to the necessity for creating powerful electric motors which are complicated and expensive to manufacture. Therefore in recent years a trend has been noted toward doing away with the electric drive and conversion to turbine drive. For this purpose the drive of the circulating pumps is made in the form of turbines fed the same steam as the main turbounit of the nuclear power plant.

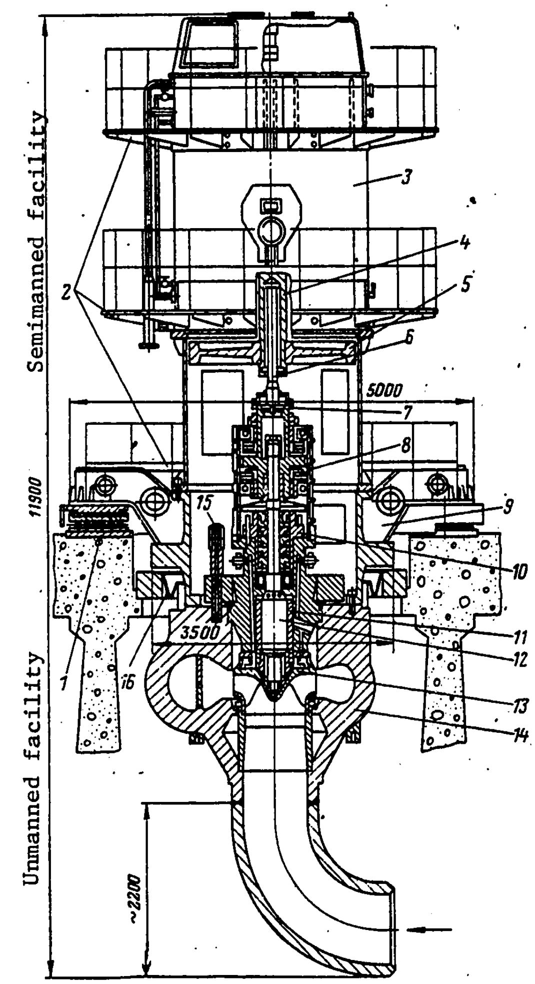


Figure 1-14. TsEN-195 main circulating pump with high flow rate (Q = 19,000 $m^3$/hr). 1--hydraulic ball-bearings; 2--service platforms; 3--electric motor; 4--electric motor shaft; 5--flywheel; 6--shaft; 7--coupling; 8--radial thrust bearing; 9--pickups; 10--seal assembly; 11--lower radial hydrostatic bearings; 12--pump shaft; 13--impeller; 14--housing; 15--pins and flange of the main parting seal; 16--diaphragm for sealing the span between floors.

The height location of the main circulating pump depends on the height at which the reactor is seated, and more precisely, the coolant input lines. The vertical height of the output connection of the main circulating pumps must be as close as possible to the level of the input line of the vessel type reactor or the distributing group plenum of a channel-type reactor. The electric drive (or the turbine drive of the two-circuit nuclear power plants) is not radioactive and requires periodic servicing. Therefore it must be separated from the active part of the pump (the impeller itself) by a shielding cover, that is, the pump drive must be located in a semimanned facility, and the impeller, in an unmanned facility.

The layout of the main circulating pump in plan view is connected with the requirement of minimum length of the main circulating circuit lines. Therefore the pumps must be installed symmetrically and as close as possible to the vertical axis of the reactor.

When designing the structural components, provision must be made for the possibility of dismantling the main circulating pump during operation. This work can be done using the bridge cranes of the reactor section through openings which must be provided for this purpose. However, as a rule, the cranes of the reactor section are heavily loaded during a shutdown period. Therefore the boxes of the main circulating pump drive are equipped with independent lifting means, the lifting capacity of which is chosen beginning with the weight of the heaviest part of the main circulating pump--the electric motor.

The thickness of the shielding between the facilities for the motors of the main circulating pump and the circulating circuit facility arises primarily from the activity of the circuit lines. For reactors with water coolant the primary source when calculating this shielding between floors (just as the other shielding structures of the coolant circuit) is the gamma quanta with an energy of 6.2 Mev from the $^{16}O(n, p)^{16}N$ reaction.

The calculated surface activity of the main circulating pump of the nuclear power plant with RBMK reactor is $1.41 \cdot 10^{-4}$ curies/cm$^2$.* The pump can be represented in the form of a cylinder 220 cm in diameter, 130 cm high and with a wall thickness of 12 cm.

During the physical startup of the Leningrad Nuclear Power Plant with RBMK-1000 reactor the measured value of the specific activity of the circulating circuit water with an electric power of 800 MW was about $10^{-4}$ curies/kg,** and the exposure dosage in the circulating circuit boxes was $(390\text{-}520) \cdot 10^{-10}$ A $\cdot$ kg$^{-1}$ (150-200 μR/sec***), in the corridors near the boxes $(0.5\text{-}1.3) \cdot 10^{-10}$ A $\cdot$ kg$^{-1}$ (0.2-0.5 μR/sec), and near the turbogenerator $(0.5\text{-}2.3) \cdot 10^{-10}$ A $\cdot$ kg$^{-1}$ (0.1-0.9 μR/sec).

Steam Generators and Separators

For all Soviet nuclear power plants with water-cooled, water-moderated power reactors, horizontal steam generators with tube banks in the form of plenums are used with submersible surface of the heat exchanger and built-in separators.

The structural design of the steam generators of the first power unit of the Novovoronezhskaya Nuclear Power Plant is presented in Figure 1-15. The heating surfaces are a U-tube system of seamless gaging pipes, the ends of which are flanged to the plenums. The coolant which is collected in the plenum moves along the pipe.

* 1 curie/cm = $3.7 \cdot 10^{14}$ Bk/m$^2$.
** 1 curie/kg = $3.7 \cdot 10^{10}$ Bk/kg.
*** 1 R/sec = $2.58 \cdot 10^{-4}$ A/kg.

In the space between the tubes the water circulation is natural. The outside surface of the tube system is flushed with feedwater converted to steam. In the steam tank a baffle separator and steam-receiving ceiling are installed over the surface of the coolant. The weight of the dry steam generator is 104.2 tons. The overall dimensions of the vessel are as follows: inside diameter 3 meters, length 11.5 meters.

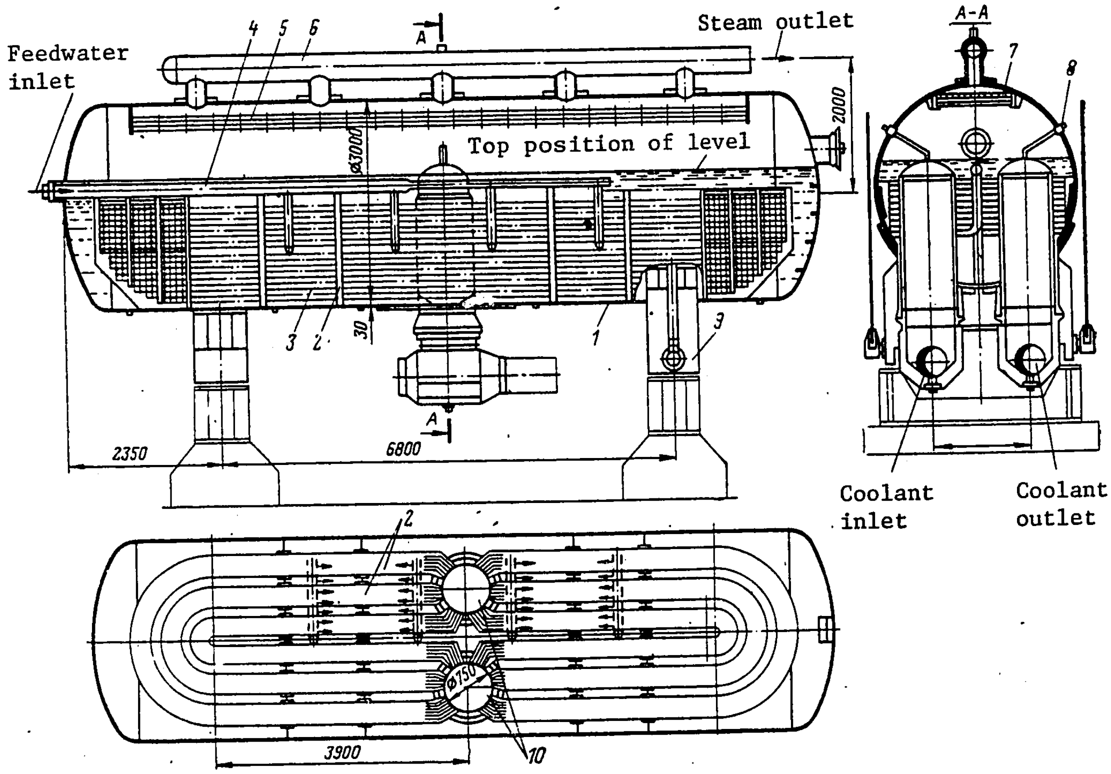


Figure 1-15. Horizontal steam generator of the first power unit of the Novovoronezh Nuclear Power Plant. 1--vessel; 2--heat exchange surface; 3--tube system supports; 4--feedwater plenum; 5--baffle separator; 6--steam intake plenum; 7--steam-receiving ceiling; 8--air connections; 9--supports; 10--inlet and exit coolant plenums.

At the nuclear power plant with VVER-440 reactors, improved steam generators are installed. Their distinguishing feature consists in the fact that the holes for servicing (inspection and repair) of the inside cavities of the pipe plenums where the most responsible joints--the ends of the heat exchange tubes--are located, are placed over the steam generator and not below it as in the steam generators of the first and second power units of the Novovoronezh Nuclear Power Plant. The weight of the dry steam generator for the nuclear power plant with VVER-440 reactors is 145 tons. The overall dimensions of the vessel are as follows: inside diameter 3.2 meters, length 11.25 meters.

For nuclear power plants with VVER-1000 reactor, a horizontal steam generator of the improved type for nuclear power plants with VVER-440 reactors but with a significant increase in the inside diameter of the vessel and two-stage steam separation was adopted. This steam generator is suspended from the ceiling of the facility, which lowers the forces on the lines on thermal expansion of it. The weight of the dry steam generator is 265 tons. The overall dimensions of the vessel are as follows: inside diameter 4.0 meters, length 16.2 meters.

At the nuclear power plant with single-circuit boiling reactors and with loop layout* of the equipment, drum separators are used to obtain the steam with the parameters required for the turbine.

At the Dresden Nuclear Power Plant (United States) a drum separator 2.44 meters in diameter and 20.4 meters long is made of carbon steel with an inside coating of stainless steel. The separation units are made of four rows of centrifugal separators and two rows of driers. The separators of the Leningrad Nuclear Power Plant with the RBMK-1000 reactor (two loops of two separators each) are made in the form of horizontal drums 2.3 meters in diameter, 300 meters long and weighing 200 tons.

The basic distinguishing feature of the steam generating equipment of the nuclear power plant with a liquid-metal-cooled reactor (BN-350) is the use of two independent units to obtain steam: obtaining, heating and steam formation take place in the evaporator, and superheating, in a steam superheater.

The steam generators of the two-circuit loop nuclear power plants and the separators of the boiling loop reactors are highly radioactive equipment, and they must be located in unmanned facilities.

The height of the steam generators of water-cooled, water-moderated reactors depends, just as the height of the main circulating pump, on the level of the exit and entrance tubes of the reactor.

The location of the steam generators and plan view is connected with the requirement of minimum length of the primary circuit lines. Therefore they are located near the reactor vessel and symmetrically around it. Above the openings of the steam generators in the ceiling there must be openings for blind flanging of the tubes in case of detection of a leak. The installation operations in the plenums of the steam generators are performed through these openings using special remotely controlled machines.

The drum separators of nuclear power plants with RBMK-1000 reactors must be located at significant height above the reactor to create an additional head. The arrangement in plan view must correspond to the same requirements as for a steam generator in loop water-cooled, water-moderated reactors, that is, minimum length of the lines to the reactor. In plan view the separators can be shifted with respect to the reactor axis for convenience of performance of operations of recharging the core.

* With loop layout of the equipment the steam generating equipment is outside the reactor vessel.

The thickness of the shielded ceiling and walls of the steam generator box of the water-cooled, water-moderated power reactors (just as the RBKM-1000) is determined by the oxygen activity of the water coolant (gamma-radiation with an energy of 6.2 Mev).

Turbines

In the early phase of the development of nuclear power engineering, in connection with the development of a large number of various types of reactors generating steam with different parameters, a large number of turbines were individually designed with a wide range of steam pressures and temperature. At the present time the following types of steam turbines have been defined for installation at nuclear power plants: with water-cooled, water-moderated and boiling reactors being the most widespread, turbines that operate on saturated or slightly superheated steam with a pressure of 5.5-7 MPa are used; with gas and liquid-metal reactors, an effort is made to use series turbines assimilated at the thermal electric power plants and operating on organic fuel--turbines with medium- and high-pressure superheated steam.

The growth of the unit power of nuclear power plants is also leading to growth of the unit power of the turbogenerators. The most economical version today is considered to be the building of a reactor-turbine monolithic unit with unit electric power of 1,000-1,300 MW.

For the turbines of single-circuit nuclear power plants operating on radioactive steam, it is necessary to build biological shielding, and the steam must be fed to the cylinder below the service level. Special requirements are also imposed on the seal of the flange connections of the steam lines (they must be replaced by welded lines insofar as possible). In the early phases of the design work it was considered that for manufacture of both the turbine itself and the entire unit it is not possible to use traditional materials in view of the danger of leaching out copper, cobalt and other materials from the structural elements of the turbine as a result of the presence of dissolved oxygen. However, the experience in operation of the turbines demonstrated that these dangers are exaggerated, and the concentration of corrosion products can be maintained at a given level by purifying all of the condensate returning to the reactor.

The basic parameters of modern Soviet condensation turbines for nuclear power plants are presented in Table 1-5.

The requirements on the layout of the turbines for the two-circuit nuclear power plants operating on nonradioactive steam do not differ from the requirements for the thermal electric power plants on organic fuel. The selection criterion is minimum expenditures on building the machine room, the steam lines and the feed lines.

Longitudinal (parallel to the longitudinal axis of the turbine room) and transverse arrangement of the turbines are possible. An analysis of the expenditures [85] for longitudinal and transverse arrangement of the turbines demonstrated that a small cost benefit can be obtained for nuclear power plants with low- and medium-pressure turbines in the longitudinal arrangement of the turbines, and for nuclear power plants with high- and superhigh-pressure turbines, with transverse arrangement of them. For 500-MW turbines, only longitudinal arrangement is expedient as a result of their significant length.

The economicalness of transverse arrangement of high- and superhigh-pressure turbines for the monolithic reactor-turbine units is explained by the high cost of the high-pressure lines. The height of the location of the turbounit is determined by the dimensions of the condenser located under the turbine.*

At the nuclear power plants with boiling reactors, all the radioactive equipment of the machine room must be placed under a shielding ceiling which must have openings for dismantling and repairing the equipment. Usually the shielding of the turbounit is not provided over the service area. However, when necessary in the operation and maintenance process, it is possible to construct a modular, collapsible concrete shadow shielding of the turbounit with a lock for the service personnel to reach the turbine on the service platform.

Table 1-5. Basic Parameters of Soviet Condensing Turbines

| Indices | K-220-44 (for nuclear power plants with VVER-440) | K-500-60/1500 (for nuclear power plants with VVER-500 and VVER-1000) | K-500-65/3000 (for nuclear power plants with RBMK-1000) |
|---|---|---|---|
| Power, electric, MW | 220 | 500 | 500 |
| Number of low-pressure cylinders | 2 | 1 | 4 |
| Total length (turbine + generator), m | 21.9 + 19.3 | 24.2 + 19.6 | 39.0 + 17.8 |
| Weight of the turbounit, tons | 788 | 1,300 | 1,524 |
| Weight of the condenser, tons | 582 | 1,120 | 1,170 |

The thickness of the shielding ceiling of the machine room and also the walls of the condensate facility is determined by calculation, and it depends on the mutual arrangement of a large number of gamma radiation sources (condenser, steam and condensate lines, recovery-heat heaters and other equipment).

Condensation Units and Service Water Supply Systems for the Nuclear Power Plants

The closed cycle of a nuclear power plant predetermines the necessity for condensation of the spent steam in the condenser and return of the condensate to the circuit. The smaller the temperature difference of the steam and the entrance and exit from the turbine, the higher its efficiency. Since the temperature depends on pressure, it is necessary to maintain rarefaction in the turbine condensers. The structural diagram of a surface condenser and the schematic diagram of the condensation unit are presented in Figure 1-16.

The spent steam is cooled by pumping cooling service (desalinated) water by the circulating pump through the condenser tubes. The steam, passing through the space

* For more details on the requirements on the layout of turbounits see [85, 87].

between the tubes, is condensed and is pumped by the condensate pump into the circuit.

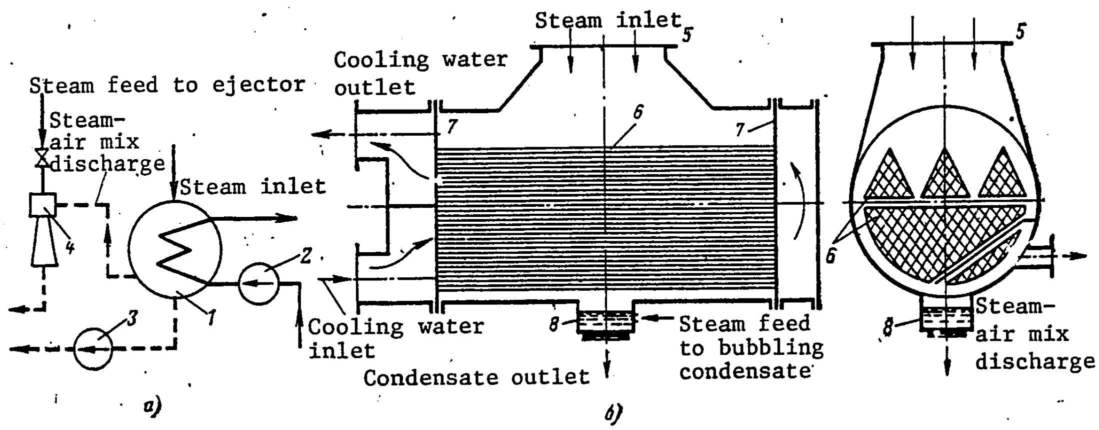


Figure 1-16. Diagram of a condensation unit (a) and structural diagram of a surface condenser (b). 1--surface condenser; 2--circulating pump; 3--condensate pump; 4--steam jet ejector; 5--flange for connection to the turbine exhaust; 6--cooling pipes; 7--pipe bank; 8--condensate collector.

The condenser must be sealed to avoid taking in air from the environment. The condensate formed with good seal of the tubes of the cooling system is distillate. For maintenance of the required vacuum in the condenser, special air evacuation units--steam-air ejectors--are used. Their operation is based on the fact that on exit from the operating nozzle of the condenser, the working steam (frequently spent from the turbine) takes away the steam-air mixture from the turbine condenser with it, creating a vacuum in it.

A defined amount of products of radiolysis and also radioactive gases enter the condensers of single-circuit nuclear power plants. Therefore, the gas mixture is removed from the condensers of the two-circuit nuclear power plants to the atmosphere, and from the single-circuit nuclear power plants, through a special ventilation system. The distillate formed in the condenser is saturated with oxygen. Partial removal of the oxygen from the condensate is possible by pumping the steam through the condensate in the condensate collector (Figure 1-16), that is, organization of bubbling of the condensate.

Along with the general requirements (ensurance of decondensation and deaeration of the condensate), special requirements are imposed on the condensation units of nuclear power plants: the possibility of taking steam discharged from the reactors or steam generators under emergency conditions and also when shutdown cooling of the reactors is required. This fact determines the peculiarities of the structural solution of the nuclear power plant condensers which depend on the type of reactor (time and conditions of its shutdown cooling). Some of the characteristics of the condensers of modern turbines are presented in [82].

The calculated specific activity of the turbine condensers of the RBMK-1000 reactor of the Leningrad Nuclear Power Plant caused by oxygen activity is $3.59 \cdot 10^{-6}$ curies/liter.

The water for cooling the condenser is collected by the circulating pump from natural water supplies near the power plant (a river, sea, lake) or from artificial water areas (reservoirs, pools). If the intake of service water for cooling and discharge of it from the condenser are realized in a natural water area, the water supply system is called direct flow.

When using artificial water supplies, the water from the condensers is sent to special units: cooling ponds, spray basins, cooling towers. After cooling in them, the water is again fed to the condensers. This water supply system is called circulating.

The water consumption and the water supply conditions depend on the power and the types of turbines and also on the adopted water supply system of the nuclear power plant.

The lower the steam parameters at the entrance to the turbine, the more water required to cool the turbounit per kilowatt-hour of produced electric power.

Modern nuclear electric power plants at which turbines operating on saturated, low-pressure steam have found application, require a very large consumption of service water for cooling. For example, when installing the turbines with a power of 300 MW with initial steam pressure of 2.9 MPa at a nuclear power plant with a power of 1,200 MW the service water flow rate for cooling the condensers will be about 500,000 $m^3$/hr.

It is natural that the water consumption also depends on the temperature of the cooling water fed to the turbine condenser. For wintertime in the central parts of the country the water flow rate in the direct flow water supply system is reduced by 50-60 percent by comparison with the summer months.

If highly mineralized seawater is used for cooling, it is necessary to use additional heat exchangers in which the seawater, moving along an open circuit removes heat from the service water designed to cool the units of the nuclear power plant and circulating through a closed circuit.

The cooling system of the condenser is selected depending on the specific conditions: climatic and natural. For example, for the middle belt of the USSR the admissible specific hydraulic load per $m^2$ of active area of the reservoir-coolers when heating the circulating water in the condensers of the steam turbine units by 8-10° C will be 0.04 $m^3/(m^2\text{-hr})$; for the spray basins under the same atmospheric conditions with a drop sprayer 0.8-1.0 $m^3/(m^2\text{-hr})$ and with a film sprayer to 6-7 $m^3/(m^2\text{-hr})$. For the most effective and most expensive ventilator cooling towers, the admissible hydraulic load will be 8-10 $m^3/(m^2\text{-hr})$.

The direct-flow water supply system is the simplest, and it is 15-25 percent cheaper than the circulating water supply, but its application is possible only when building nuclear power plants near large water supplies. The possibility of water supply through a direct-flow system is also determined by the specifications of the Gosrybnadzor [State Fishing Inspectorate]: the temperature in the water must not rise by more than 5° C during the summer as a result of the discharge, and it must not rise by more than 3° C in the winter; in this case the minimum flow rates of the river in the low-water period must exceed the demands of the electric power plant for water by no less than two-three times.

The service water can be supplied through closed water lines or with gentle relief and large flow rates, along a supply canal. The water can also be removed by a canal where the water discharge must be no closer than 40 meters to the water intake (Figure 1-17). A transfer canal is used to transfer the hot water to the water intake during the winter to control the frazil ice.

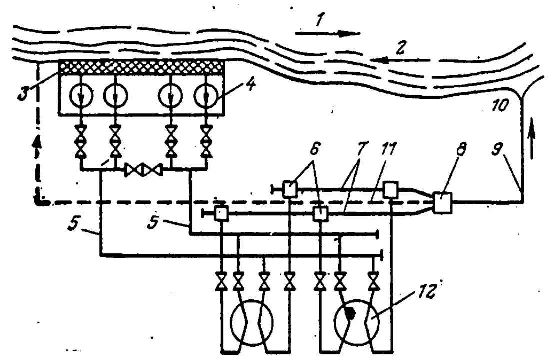


Figure 1-17. Water supply system using rivers and reservoirs. 1--current in the river with the direct-flow system; 2--current in a cooling pond with circulating system; 3--screens; 4--circulating pumps; 5--delivery lines; 6--discharge siphon wells; 7--discharge water lines; 8--switching sump; 9--discharge channel; 10--water outlet; 11--transfer drainage canal; 12--turbine condensers.

The circulating water supply system finds broad application in the construction of large condensation nuclear power plants in densely populated areas in the absence of reliable water supplies and also when building ATETs which are located near populated areas.

For the circulating water supply system, the irrecoverable losses of water which must be made up from the outside, amount to 4-5 percent of the total circulating water flow rate for cooling towers, 5-6 percent for spray basins, and 0.7-0.8 percent for cooling ponds.

The cooling ponds find the broadest application for the circulating water supply of powerful nuclear power plants. In order to increase the relative cooling area of the cooling ponds, special jet-guiding dams are built which deflect the flows of discharge water from the condensers away from the water-receiving devices.

The depth of the cooling pond must be no less than 3 meters. It is necessary to provide for the possibility of filling it from inflowing streams or springs or by artificial water supply. If it is impossible to build a cooling pond, a circulating water supply is used with the application of cooling towers which can have artificial and natural drawing of air through them. In the cooling towers with artificial draft, the air circulation is provided by fans which makes it possible to decrease their height.

The schematic diagram of the circulating water supply with cooling tower is presented in Figure 1-18. Depending on the method by which the contact surface of the cooled water with the air is achieved, the cooling towers are divided into drop- and film-type cooling towers. The most widespread at the large nuclear power plants are the film-type towers which have better technical-economic indices than the drop towers and, especially, the spray basins.

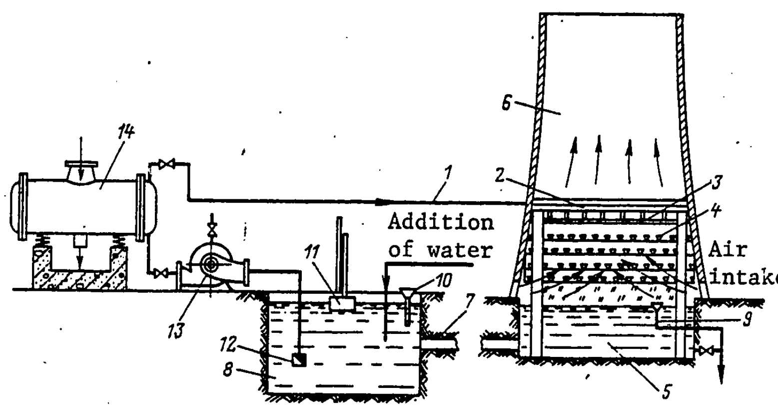


Figure 1-18. Circulating water system for the circulating water supply with a cooling tower. 1--delivery lines; 2--flume with discharge tubes; 3--spray heads; 4--lattices; 5--collection basin; 6--exhaust tower; 7--water supply channel; 8--water-receiving sump; 9--blowing; 10--calcium hypochlorite input; 11--level indicator; 12--pump receiving valve; 13--circulating pump; 14--turbine condenser.

When it is necessary to build nuclear power plants in waterless areas, systems with cooling of the water in Heller towers or fan towers can be used. The water flow rates for makeup of such cooling systems are much lower than for ordinary cooling methods, but the effectiveness of the cooling is reduced, and the electric power generation of the nuclear power plant is reduced, correspondingly, and the electric power consumption for the circulating systems of this type increases sharply. In this case, along with using a circulating system, it is possible to use a mixed water supply system; during the low-water periods part of the warm water is discharged into the river above the water intake and after mixing with the cold river water it is again fed to the electric power plant.

In addition to cooling the turbine condensers, the service water is needed at the nuclear power plant to cool the equipment. In cases where this equipment is part of the safety system of the electric power plant, special requirements are imposed on the reliability of the cooling water feed. The guaranteed water feed under emergency conditions and if the electric power plant is deenergized is provided by installing emergency service water pumps, three independent groups for each power unit. In order to prevent simultaneous failure of all the pumps in the case of a fire, each group of pumps is installed in isolated facilities. All of the emergency pumps for the service water supply are connected to a reliable power supply from a diesel electric power plant. The degree of reliability of the water supply must be very high; therefore in case of an emergency with the hydroengineering structures which can lead to loss of water in the basic service water source, it is necessary to provide for water to be obtained from a reserve water supply.

Equipment of the Condensation-Feed Channel

The entire water feed channel from the condenser to the steam generator (or separator of the single-circuit nuclear power plant) is called the condensation-feed channel (see Figure 1-9), and the part of the circuit from the condenser to the deaerator is called the condensation part, and from the deaerator to the steam generator (separator), feed.

The heat transferred in the condenser to the cooling water is irreversibly lost. The heat losses can be reduced by directing part of the steam into the recovery-heat heater system. The low-pressure recovery-heat heaters are installed between the turbine condensers and the deaerators, and the condensate is heated in them by tapping steam from the low-pressure cylinders of the turbine. The high-pressure heaters are located between the deaerators and the steam generators, and they are fed steam from the high-pressure cylinders of the turbine.

The recovery-heat heaters used at nuclear power plants are surface heat exchangers, the advantage of which is the possibility of operation independently of the water and heating steam pressures. The water can be pumped through several heaters by a single pump.

The recovery-heat low-pressure heaters are made with tube banks located inside the vessel. The steam from the taps of the low-pressure cylinders of the turbine is fed upward to the heater, it washes over the U-tubes through which the feedwater passes. The condensate is collected in the lower part of the heater and by gravity or by means of a drainage pump it goes to the space between the tubes of the next feedwater heating stage. From the last heater the drainage is sent to the turbine condenser.

The high-pressure recovery-heat heaters are made with plenums to which the horizontal coils of tubes made in the form of spirals are connected. The steam washing over the coils is condensed. The recovery-heat high- and low-pressure heaters have a removable top cover which permits repairs to be made easily.

The basic characteristics of the low- and high-pressure heaters are presented in [82].

The recovery-heat feedwater heaters must be located near the turbounit and the condenser of the turbine, for the heating is done by steam picked up from the turbines. In the ceiling over the heaters there must be holes left for possible dismantling of them for repairs. The installation of the heaters is by the machine room crane equipment.

The recovery-heat heaters of single-circuit nuclear power plants, which are sources of radiation, are located in unmanned facilities under the shielding ceiling of the machine room, the thickness of which is determined considering the location of the sources (the turbine condensers, the live steam lines, the feedwater lines, and so on).

The deaerators are designed to remove dissolved gases from the feedwater, for mixing condensate of different temperature, pressure, gas content and also heating the feedwater. At the nuclear power plant usually thermal mixing deaerating columns are used with a pressure of 0.4-0.7 MPa combined with deaeration feeder tanks for collecting condensate. The basic parameters of the deaeration columns of the Chernovitskiy and the Barnaul plants and also the deaerator tanks are presented in [82], and the plate-type deaeration column is diagrammed in Figure 1-19.

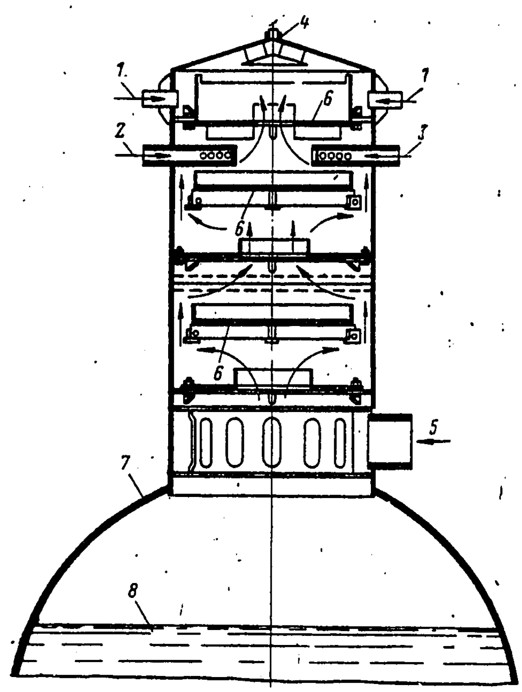


Figure 1-19. Diagram of a deaeration column with tank. 1--supply of the basic feedwater flow; 2--supply of condensate from the high-pressure heater; 3--supply of evaporator condensate; 4--connection for vapor discharge; 5--heating steam feed; 6--plates with holes; 7--deaerator tank; 8--feedwater level in the tank.

The water to be deareated is fed to the upper part of the column through pipes, and it drains subsequently through the plates with holes (perforated panels). During movement of the streams downward through the plates the water is heated to the saturation temperature. The water released from the gases is collected in the deaerator tank located under the column. The heating steam, rising upward through the gaps between the plates alternately intersects the jets of falling water. The uncondensed steam together with the gases is discharged through the connection pipe to the vapor cooler.

The deaerator, which has a significant reserve of seawater usually is placed on the upper levels of the stack of electrical units (or, as it is called, the deaerator stack) in order to increase the pressure at the input of the feed pumps.

Lifts are required to service the deaerators, the lifting capacity of which is determined by the weight of the dry deaeration column.

The generally accepted arrangement of the deaerators has two deficiencies:

in case of a possible loss of seal of the deaerator, the water can get into the lower facilities where the electrical units are located;

the filled deaerator tanks located at the higher levels, transfer significant static loads to the structural elements, which contradicts the basic structural principle of placing light equipment at the upper levels and heavy equipment at the lower levels. The large volumes of shielding around the deaerators for nuclear power plants with single-circuit boiling reactors cause additional loads on the lower structural elements.

## 1-3. Characteristic Features of the Engineering Equipment

The engineering equipment includes auxiliary systems that provide normal conditions for the service personnel and also required to accomplish the basic production process. This includes the service and drinking water supply, lighting, process and general exchange ventilation, sewage and heating.

A distinguishing feature of a nuclear power plant is radioactivity of the coolant (and the working medium of the single-circuit nuclear power plants) with the formation of liquid, solid and gaseous waste, losses of which in the production process are unavoidable.

In order to remove the radioactive waste at a nuclear power plant, in addition to the ordinary engineering equipment systems, special systems are built which are specific to the nuclear plants--special process ventilation, special sewage and a system for deactivation and burial of radioactive waste.

### Special Ventilation

Whereas solid and liquid waste can be comparatively easily localized in closed containers (tanks, pipelines), air pollution with radioactive materials (gases or aerosols) can be significant.

Special ventilation at a nuclear power plant is designed for purifying the air and creating safe and normal working conditions for the service personnel.

At the nuclear power plant, the radioactive waste can get into the air as a result of leaks of radioactive coolant containing gaseous and aerosol fission products (xenon, krypton, iodine, and so on) and also during operation of the auxiliary units (the "dirty" condensate tanks, the fuel element holding pools, and so on). Another source of air pollution is the formation of gaseous radioactive isotopes (above all, argon-41) and radioactive aerosols of complex isotopic composition on irradiation by neutrons of elements entering into the composition of the air and dust.

The usual method of controlling air pollution is purification of the air by filters or dilution by pure air to permissible concentrations.

However, since the entry of radioactive materials having high toxicity into the air of the work spaces of nuclear power plants is significant, normal conditions in the nuclear power plant facilities can be created primarily as a result of sealing the equipment, placement of it in sealed boxes with remote control, zonal planning, and with such measures ventilation can have only auxiliary significance.

As experience shows, the air of the work areas in nuclear power plants is basically polluted in connection with loss of seal of the equipment and boxes when performing preventive maintenance and repair operations. Taking this fact into account and also beginning with the requirements of not allowing irradiation of the personnel by external or internal sources of radiation above the permissible limit, at the nuclear power plant, just as at any nuclear installation, it is necessary to site the equipment by the zonal principle (see Chapter 3) with all of the facilities being broken down into zones with strict and free conditions and, in turn, the facilities in the strict conditions zone are divided into unmanned, semimanned and manned facilities. The requirements on the radioactive materials concentration in the air of the zone where highly toxic unmanned equipment is located can be reduced. The maximum concentration level here will be determined by the condition of not allowing activity to accumulate. It is necessary to ensure permissible concentrations of radioactive materials in such facilities only for the short time interval required to service the equipment.

Accordingly, several ventilation systems are set up at the nuclear power plants, each of which has defined purposes:

the constantly operating special process ventilation systems for maintaining given concentration levels of radioactive materials during normal operation of the nuclear power plant;

periodically operating process ventilation systems which are switched on for preventive repairs or when recharging the reactor core;

special gas purification designed to remove radioactive and explosive gases with the air directly from the points of their formation (blowdown of the reactor, the dirty condensate tanks, and so on) and purification on special units.

The normative materials [59] have established the maximum permissible intake of radioactive materials by the organism of man and the mean annual concentrations of radioactive materials in the air and water around nuclear power plants. Therefore the air from the ventilation system which is to a defined degree enriched by radioactive isotopes must be diluted before it is released into the atmosphere. For this purpose air from the ventilation system which has been previously purified by the filters (if required) is directed to the exhaust vent pipe and ejected into the upper layers of the atmosphere. The height of the vent pipe of a nuclear power plant is determined from the condition of dilution of the stream of ejected air to the permissible limit when it settles to the surface of the ground.

The special ventilation must also provide for admissible temperatures in all of the strict conditions areas (the dirty zone): no more than 50° C in the semimanned areas and no more than 70° C in unmanned areas.

Special Features of Nuclear Power Plant Ventilation Systems and General Design Principles. Two types of nuclear power plant ventilation are distinguished:

local exhaust ventilation designed to remove the air from the shelters over places that release radioactive gases, vapor, aerosols and excess heat. The concentration of the radioactive materials in the air removed by the local exhaust ventilation can exceed that permitted by the sanitary norms by many times. Therefore, as a rule, such air is subject to purification before ejection into the atmosphere;

the general exchange intake-exhaust ventilation which prevents the permissible concentrations of radioactive materials from being exceeded in the manned and semimanned facilities by dilution of the polluted air with pure air.

The basic operating principle of the ventilation system of nuclear power plant buildings is maintenance of increased pressure in the facilities with minimum possible pollution and sufficient rarefaction in the facilities with maximum possible pollution, which is realized by the forced intake of pure air in the cleanest areas and exhaust from the dirtiest areas. The transfer of air from one facility to another must be organized so that when one or two fans fail, the air from the dirtier facilities cannot get into the cleaner ones. For this purpose, check valves are installed in the openings in the walls between the facilities (excess pressure valves), which open under the effect of a pressure difference in adjacent facilities of no less than 50 Pa. The excess pressure valves (KID) are produced for openings with a diameter $D_y$ from 100 to 400 mm with 50-mm spacing.

The three-zone planning of the nuclear power plant facilities makes it possible to use a staged ventilation system or a system for direct supply of air to the zones.

In the staged ventilation system the intake air is fed to the manned facilities, and it is removed through the semimanned and unmanned facilities. The air from the manned facilities goes to the semimanned facilities through excess pressure valves installed in the wall between the zones as a result of the pressure difference; it goes from the semimanned to the unmanned facilities through analogous valves. The manned facilities do not communicate with the unmanned facilities even through filters.

With the direct feed system the air is supplied individually to each facility and removed from it. This system is used only on imposition of especially strict requirements on the isolation of the manned facilities from the semimanned facilities and when these facilities are separated by massive shielding walls. The air balance by zones in this case is as follows: the inflow to the manned facilities exceeds the exhaust (approximately twofold exchange per hour), and in the semimanned facilities the exhaust is greater than the inflow.

The advantages of staged ventilation by comparison with direct supply of air to the zones can include the following:

a decrease in the total volume of ventilating air, for it is first used to ventilate the manned facilities and then the semimanned and unmanned facilities;

a reduction in cost as a result of a smaller number of ventilation systems.

However, the staged ventilation must be used only with round-the-clock operation of the system, for in shutdown periods it would be possible for the dirty air to leak from the unmanned facilities into the manned facilities or from the unmanned into the semimanned facilities through cracks or failed excess pressure valves which is inadmissible.

The choice of output capacity of the units for general exchange ventilation of the reactor rooms of nuclear power plants and also the machine rooms of the single-circuit nuclear power plants must be made considering the necessity for recharging the core and the performance of repair operations beginning with the following multiplicities of air exchange:

| Volume of Facility, $m^3$ | Multiplicity of Air Exchange, 1/hr |
|---|---|
| To 100 | 10 |
| 500 | 5 |
| 1,000 | 3 |
| 5,000 | 2 |
| 10,000 or more | 1 |

When recharging the fuel and when performing the repair operations in the reactor sections and also the machine rooms of the single-circuit nuclear power plants no less than twofold air exchange per hour must be ensured, and for repair operations in the steam generator and main circulating line areas of the two-circuit nuclear power plants and also in the majority of unmanned areas of the single-circuit nuclear power plants three- to fivefold air exchange per hour must be provided.

All of the exhaust and intake systems of the dirty zone are equipped with reserve ventilation units, and the exhaust ventilation systems which service the responsible users (the control panel, the SUZ cooling and other manned facilities of the primary circuit) are connected to a reliable electric power supply network, and they are equipped with automatic starters after the power supply has been interrupted.

The local ventilation in the unmanned and semimanned facilities of the dirty zone must provide for rarefaction with respect to the provisionally clean facilities equal to no less than 30-50 Pa (3-5 mm of water). The calculated multiplicity of the air exchange in the semimanned facilities is determined beginning with the nature of the facility. However, the air flow rate must be such that the velocity of the air in the opening will be no less than 0.2 m/sec.

Frequently in the unmanned facilities of nuclear power plants there is equipment with large heat releases (the separator boxes of nuclear power plants with RBMK-1000 reactors, the pipeline corridors, and so on). For such facilities it is inexpedient to provide cooling by a common ventilation system. In these cases it is permissible to build a recirculating air-cooling system in which the air is cooled by service water or water from refrigeration units. For the two-circuit nuclear power plant with water-cooled, water-moderated power reactors it is possible to combine the recirculating cooling systems of the reactor pit and the steam generator box.

In facilities with constant release of aerosols and radioactive gases in which it is possible for people to be present (the envelope over the reactor, the steam generator box of nuclear power plants with water-cooled, water-moderated power reactors, and so on), a recirculating filter system is installed to purify the air. This system must have redundant fans and filters. At the entrance to these facilities, connections are installed for the individual protection means (air suits, air helmets). The output capacity of the air supply system to the air suits must be no less than 15 $m^3$/hr per suit, and the pressure at the connection point, no less than 4.5 kPa (450 mm of water). The intake of air for the air suits can be from any intake ventilation chamber through an aerosol fabric filter.

In the process of performing the recharging and repair operations, additional air flow rates are required. For these purposes repair ventilation is installed which is switched on for the time that these operations are being performed. The hourly capacity of this system must be no less than one volume of the largest of the manned facilities.

In order to prevent the escape of radioactive gases and aerosols from the fuel holding and recharging pools, an air curtain is designed over them. The removed air is directed into the repair ventilation system. During the repair operations the exhaust ventilation systems in the openings of the unmanned facilities must create an air velocity of no less than 1 m/sec.

The air ducts of the local exhaust ventilation become polluted with radioactive aerosols during operation, in connection with which it is necessary to provide biological shielding around them. Usually when trying to keep down the capital expenditures, the exhaust ventilation ducts are built inside the massive concrete shielding walls or in underground corridors.

When routing the air ducts it is necessary to consider that the intake ventilation ducts cannot be laid through the unmanned facilities, and the local ventilation ducts, in manned facilities.

In addition to shielding it is necessary to provide for the possibility of deactivating the local exhaust systems. For these purposes, special hatches are constructed in the air ducts and their shielding, and the air ducts are laid with a slope in the direction of the drainage traps which are used to remove the deactivating solutions or condensate which are used to wash out the air ducts and for special air purification.

The presence of chemically active materials in the deactivating solutions and in the air removed from various enclosures and also the presence of radioactive materials in it impose special requirements on the materials from which the air ducts of the local exhaust ventilation are made.

The materials must not be subjected to the chemical effects of acids or bases; they must have sufficient radiation resistance and low absorption capacity. These conditions are set aside by expensive steel and aluminum. Recently the possibility has appeared for the use of chemically stable polymer materials to line the air ducts.

Filters. Depending on the requirements on the degree of removal of pollutants from the air and also materials used for filtration, the filters can provide both fine and rough purification.

Special fabrics based on polyvinyl chloride and acetylcellulose are used to construct the fine purification filters.

For the rough purification filters, a fibrous packing of fiberglass or lavsan waste is used.

The frame-type filters have become the most widespread. The filter fabric is stretched on Π-type wooden frames, and the filter with the required filtering area is assembled from these frames by successive rotation of each of them by 180°. The spent filters can be destroyed by burning with subsequent purification of the combustion products.

Vent Pipes. As has already been stated, the dilution of radioactive discharge to permissible concentrations at ground level is ensured by using vent pipes at the nuclear power plant.

The dispersion of the radioactive materials in the atmosphere depends on the wind velocity and the height of the pipe. The velocities and prevailing directions of the winds can be determined from climatic reference data where the wind velocity is presented at an altitude of 10 meters from ground level. At other altitudes the wind velocity is determined by introducing a correction factor which varies within the limits of 0.666 (for a height of 2 meters) to 1.8 (for a height of 200 meters). The wind direction is determined from the "wind rose" on the points of which the prevailing monthly, quarterly or annual wind direction is plotted.

When developing the master plan for a nuclear power plant it is necessary to consider the prevailing wind direction so that the vent pipe and the "dirty" buildings will be located downwind from the "clean" buildings at the electric power plant site and the housing facilities.

The calculation of the vent height for given discharge can be made by the procedure discussed in [47]. When calculating the vent pipes it is possible to use the data presented below on maximum permissible discharges, curies/day, at nuclear power plants with a vent pipe 100 meters high:

| | |
|---|---|
| Total strontium-90, strontium-99 | $10^{-3}$ |
| Iodine-131 | 0.1 |
| Total beta- and gamma-active isotopes, except strontium and iodine isotopes | 0.5 |
| Total radioactive inert gases (krypton, xenon and argon isotopes) | 3,500 |

The daily discharge of all groups of isotopes simultaneously is permissible, but it must not exceed the values indicated in the table with respect to each group.

Special Gas Purification. During normal operation, the radioactive process gas blowoffs are partially directed into the special ventilation system. However, during recharging or when a significant number of fuel elements are unsealed, the gas activity in the vent pipe discharge can increase sharply, primarily from iodine and inert gases. In this case a special gas purification system is used to purify the air.

The removal of inert gases from the air is possible by pumping them into gas holders and holding it there for several hours. During this time the radioactive decay of the gases takes place with the formation of materials which can be trapped by the aerosol filters. For large nuclear power plants holding the radioactive gases in the gas holders is combined with adsorption of them on adsorber filters where activated charcoal is used as the sorbent. The main process equipment of the special gas purification system must have 100-percent redundancy.

The fans and filters of the intake and exhaust ventilation systems at nuclear power plant buildings must be combined in centralized intake and exhaust ventilation centers, the location of which in separate buildings is possible. In the case where they are placed in the nuclear power plant buildings it is necessary to be guided by the following principles:

the chambers of the intake systems (the intake ventilation center) must be located at the top levels of the building on the windward side;

entrance to the intake ventilation center must be provided from a clean zone;

the exhaust ventilation center must be located on the downwind side of the building in the reactor section near the vent pipe.

The fans and filters of the exhaust systems of the unmanned facilities must be located in a separate box with biological shielding. The drives and electric motors of these fans must be located in manned facilities.

To allow for the possibility of installation, dismantling and repair, all of the fans weighing more than 50 kg must be in range of the lift machinery. It is necessary to provide openings over the filter storages.

It is expedient to locate the gas holders of the special gas purification system near the exhaust vent pipe.

Radioactive Waste

The operation of a nuclear power plant is accompanied by the formation of a significant amount of radioactive solid and, primarily, liquid waste. Therefore when designing nuclear power plants, in addition to the foul sewage and industrial waste sewage, a system must be planned which provides for the collection, transportation and burial of radioactive waste.

Liquid waste formed during operation of the nuclear power plant is considered to be radioactive if the radioactive materials content in it exceeds the mean annual permissible concentrations established for drinking water and the water in open water areas [59].

The solid waste of nuclear power plants (the materials of the core, the reactor, dismantled equipment, and so on) are considered to be radioactive if the exposure dosage of gamma radiation at a distance of 10 cm from their surface exceeds 2.8 $A \cdot kg^{-1}$ (0.3 mR/hr).

Depending on the total specific activity, the liquid waste is divided into three categories: slightly active to $10^{-4}$ curies/liter,* medium active from $10^{-4}$ to 1 curie/liter and highly active, more than 1 curie/liter. The highly active waste is not formed directly at the nuclear power plant.

Depending on the exposure dosage of the gamma radiation at a distance of 10 cm from the surface, the solid waste is divided into slightly active from $0.28 \cdot 10^{-4}$ to $280 \cdot 10^{-4}$ $A \cdot kg^{-1}$ (from 0.03 to 30 mR/hr), medium active from $280 \cdot 10^{-4}$ to $9.28 \cdot 10^{-4}$ $A \cdot kg^{-1}$ (from 30 to 1,000 mR/hr) and highly active, over $9.28 \cdot 10^{-4}$ $A \cdot kg^{-1}$ (>1,000 mR/hr). The radioactive waste formed during operation of the nuclear power plant is distinguished not only with respect to phase composition and activity, but also with respect to radiochemical and chemical composition.

Liquid Radioactive Waste. The sources of the formation of liquid radioactive waste at nuclear power plants are the blowdown systems of the reactor and auxiliary equipment, purification systems for the organized leaks, special water purification, deactivation, showers, special laundry, and so on.

The total volume of radioactive wastewater subject to localization at large modern nuclear power plants does not exceed 500 $m^3$/day with a specific activity of $10^{-5}$ to $10^{-6}$ curies/liter. The one-time discharges can be 1,000 $m^3$.

The planned radioactive leaks must be removed by the organized leak system to special tanks. They are not mixed with other water, if necessary they are purified and returned to the circuit.

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* The upper activity limit of slightly active waste at the present time has not been determined and fluctuates in the USSR from $10^{-5}$ to $10^{-4}$ curies/liter. In the United States waste with an activity of several millicuries per liter is considered to be slightly active waste.

The water and solutions getting on the floor of the facilities in case of leaks (unorganized leaks) or deactivation of equipment are collected by the gravity flow sewage system in separate tanks.

In order to exclude water from one facility getting into another through the special sewage system it is necessary to provide a system of hydraulic back-pressure valves. The air from the tanks with an activity of more than $10^{-7}$ curies/liter is sent to the special ventilation system.

The medium active waste (more than $10^{-5}$ curies/liter) is collected in stainless steel or carbon steel tanks with reliable anticorrosion coating. The facilities for installation of the tanks are equipped with carbon steel trays. The capacity of the trays is determined from the leakage conditions of the largest tank installed in the facility.

All of the liquid waste is subjected to deactivation in the purification structures, and the purified water must be returned to the production cycle. Purified unbalanced water from the decontamination locks, decontamination stations, special laundries and laboratory sinks which by agreement with the Gossannadzor [State Sanitary Inspectorate] can be discharged into the industrial service or foul sewage system after dosimetric monitoring in an intermediate tank, constitute an exception. In connection with the different nature and degree of contamination of the circuit, trap, laundry and other water, separate special sewage systems are designed for them.

Internal Special Sewage Networks. For the internal special sewage networks located at points that are inaccessible for repair, stainless pipe is used. It is also possible to use thick-wall carbon steel pipe to transport nonaggressive waste. Traps made of stainless steel are installed in the unmanned facilities, and traps made of steel or cast iron are installed in the decontamination stations and the semimanned facilities.

The pipe diameters and the slopes of the gravity feed internal special sewage network are taken in accordance with the effective norms for designing the internal industrial sewage networks with complete emptying of the tubes.

When laying the internal special sewage networks it is necessary to strive to group them and lay them in pipe corridors. The necessity for constructing biological shielding for the special sewage networks is established by physical calculations.

Open laying of the special sewage lines for transporting slightly active waste in the semimanned facilities with mandatory special painting of them is permitted.

On intersection of the shielding walls by the special sewage network, possibilities of local radiation leaks must be excluded.

The drives for the special sewage cutoff valves are located in the semimanned or manned facilities.

The floors in the facilities where the traps are installed must be made with a slope in their direction of no less than 0.01, and the top of the trap grating must be 5-10 mm below the clean floor level.

The ventilation of the special sewage lines with an activity of less than $10^{-7}$ curies/liter is realized through ordinary standpipes. For higher activity the air from the special sewage is sent to the special ventilation system.

If it is impossible to organize a gravity special sewage system, pumping transfer stations are used. When pumping waste with an activity to $10^{-5}$ curies/liter, submersible pumps are used, and with an activity of more than $10^{-5}$ curies/liter, air lifts or packless pumps are used.

Outside Special Sewage Networks. The purpose of the outside special sewage networks is to transport radioactive waste to the storage facilities or waste processing points. The outside networks are divided by nature of operation into pressure and gravity networks and also those operating constantly or periodically. In addition, they must be divided with respect to activity, aggressiveness, temperature and mechanical contamination content.

By designation the special sewage waste is divided into process waste which is stored, slightly contaminated waste which is purified and also slurries, acids and bases, desorbing solutions, return water, condensate from the special ventilation, and so on [9].

The special sewage lines for the low-active liquid waste can be laid directly in the ground above the groundwater level. In the case of activity of the waste of $10^{-4}$ curies/liter and higher or when building a special sewage system for slightly active waste in water-saturated ground the special sewage lines are laid in reinforced concrete conduits lined with stainless steel or with epoxy coating (Figure 1-20) to keep the liquid waste out of the soil in case the sewage line leaks.

In addition, this construction makes it possible to deactivate the inside surfaces of the conduits.

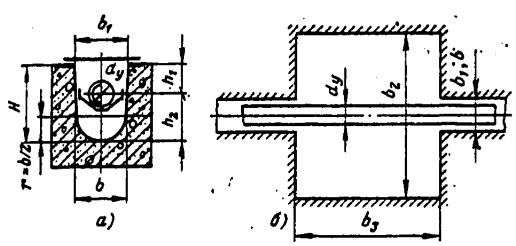


Figure 1-20. Conduits and pits of special networks with pipelines $d_y$ = 40-200. a--section of the conduit with epoxy coating (for channels lined with stainless steel $b_1$ = b); b--plan view of the installation-welding pit (height of the pit chamber is equal to the height of the channel). For the dimensions see Table 1-6.

Table 1-6. Dimensions of Reinforced Concrete Conduits and Pits for the Special Sewage System (Figure 1-20)

| Provisional Diameter of Special Sewage Pipes $d_y$ | Cross Sectional Dimensions, mm | | | | | | |
|---|---|---|---|---|---|---|---|
| | $h_1$ | $h_2$ | $H$ | $b$ | $b_1$ | $b_2$ | $b_3$ |
| 40—70 | 100 | 200 | 300 | 200 | 216 | 600 | 600 |
| 100—125 | 100 | 250 | 350 | 200 | 216 | 600 | 600 |
| 150 | 150 | 300 | 450 | 250 | 270 | 700 | 700 |
| 200 | 150 | 300 | 450 | 300 | 320 | 800 | 800 |
| >200 | 190 | 260 | 450 | 400 | 420 | 900 | 900 |

In the straight sections the conduits are made of prefabricated reinforced concrete blocks 6, 4 and 2 meters long. For installation and welding of the pipelines it is necessary to build installation-welding pits. The spacing between them must be 50-100 meters. The dimensions of the conduits and the pits when laying one special sewage line as a function of its diameter are presented in Table 1-6.

The special sewage networks must be laid with a slope in the direction of the collection plant which is no less than 3 mm per meter of running length.

The lines are installed in the conduits on moving and stationary supports tack welded to the fittings in the walls of the conduit. The stationary supports which are used to restrict deformations of the pipes during thermal expansion are installed every 50-70 meters.

Inspection and emergency pits are installed along the length of the special sewage route. The spacing between these pits must be no more than 100 meters for pipe up to 500 mm in diameter and 200-250 meters for pipe more than 500 mm in diameter. In the emergency pits dosimetric monitoring instruments are installed, the readings of which are transmitted to the dosimetric monitoring station of the nuclear power plant.

It is necessary to consider the following when routing the medium- and high-activity sewage networks:

the special sewage networks must be laid along "dirty" paths. The distance from the domestic and drinking water lines must be no less than 3 meters in the case of channel laying of the pipes and 5 meters in the case of channelless laying in clayey soil and 10 meters for channelless laying in percolating soil;

on intersection with the special sewage lines the water lines must be laid above in a shielded metal jacket (pipe in pipe);

the depth of the special sewage networks is determined by the heat engineering calculations under conditions of observing the PDU at ground surface and in the pits. The dosage at the surface of the ground or the cover of a pit must not exceed $1.03 \cdot 10^{-10}$ A $\cdot$ kg$^{-1}$ (0.4 μR/sec), and in a pit $7.22 \cdot 10^{-10}$ A $\cdot$ kg$^{-1}$ (2.8 μR/sec). In all cases the thickness of the fill over the special sewage network must be no less than 70 cm. The recommended depth of the special sewage is about 4 meters.

The concentrated solutions are transported using packless (sealed) pumps or compressed air.

In the case of concentrated solutions with high salt content, to avoid fouling of the pipes with precipitating crystals it is necessary to install a final evaporator for the solutions directly before they are fed to storage. This type of evaporator, in particular, has been provided at the Leningrad Nuclear Power Plant.

Storage of Liquid and Solid Waste. For concentrated solutions and for slurries, the following methods of storage and removal are permissible: temporary storage in tanks, deep storage (burial), solidification by the methods of bituminization or cementing with subsequent burial.

The tanks for storing liquid and solid waste are designed for no less than 5 years of operation of the nuclear power plants considering the possibility of expanding the plant during operation. The waste storage pits at the power plant site are located considering the zonal planning of the master plan (see Chapter 2) necessarily within the limits of the secured zone of the enterprise or in a separate secure zone in an area with low groundwater level. The permissible distance of the storage pits from the water mains is no less than 50 meters and from open water areas, 500 meters. The lowest level of storage of liquid waste is 4 meters above the highest groundwater level. The tanks must be located only underground.

For storage of concentrated solutions two types of storage pits are used. The first type has the tank installed directly in the ground; the second type has the tank installed in a special facility (the casemate-type tank). The casemate-type tanks, as a rule, are used to store highly active liquid waste.

For the storage of slurries, both ordinary tanks and tanks with a drainage system and a special system for pumping out the clarified solution after settling and consolidation of the suspensions are used. The clarified, drained filtrate is pumped from the pit to the bottom of the reservoir, as a result of which the bottom is designed with a slope in the direction of this pit. For pumping the remaining clarified solution from different levels (as the consolidated suspensions accumulate), intake lines are provided. Other structural features of the tanks and the remaining storage pit construction depend on the level of activity and type of radiator (alpha, beta, gamma). Thus, the tanks, equipment and service lines for liquid waste with alpha-radiators without noticeable gamma-radiation do not require special shielding, but they require reliable seal; for highly active waste with gamma-radiators biological shielding is required. For removal of the released heat, explosive hydrogen and other gases from the tanks, special arrangements are provided.

The operating experience of the storage pits in the USSR indicate that the temperature of highly active liquid waste contained in the tanks is, as a rule, close to 50° C. In order to maintain such a temperature in the highly active waste it is necessary to remove excess heat. This is done by special cooling systems.

For liquid waste with an activity to 8 curies/liter the heat can be removed by process ventilation, blowing with air over the surface of the solution in the tank. The multiplicity of the air exchanged in this case is determined by the heat engineering calculations. For more highly active waste the heat is removed by coils with water cooling.

The dilution of hydrogen to explosion-safe concentration and its removal are accomplished by special process ventilation. In order to avoid the formation of pockets for the accumulation of explosive gases in the points of maximum rise of the surface of the tank cover pipes are cut in to exhaust these gases.

The construction material for tanks, lining and other parts of the storage pit is selected depending on the characteristics of the liquid waste medium (acid, neutral, basic).

For acid solutions, the tanks, their lining, lines, and so on are made of corrosion-resistant steels, the types of which are determined depending on the chemical composition of the acids and their concentration and also the temperature of the solution.

For neutral and alkaline solutions, low-carbon steel can be used. In Soviet practice the storage tanks made completely of carbon steel have not become widespread, but in some of the constructed storage pits the tanks (with a capacity of 6,000 $m^3$) are lined with carbon steel. At a number of the electric power plants where the waste is converted to the alkaline state for safety reasons, corrosion-resistant steel is still used to line the tanks.

Taking advantage of Soviet and foreign experience, it is necessary to more broadly introduce low-carbon steel for building storage pits. For this purpose it is necessary to improve the operating culture of the storage pits and also to take measures to prevent the steel from corrosion. Such measures include primarily painting with radiation- and acid-resistant paints and coatings based on epoxy resins.

In each individual case the choice of material for the tank or for lining it and also the chemical protection of carbon steel are determined by the process engineer beginning with the corrosiveness of the medium and the operating time.

In USSR practice the storage pits are designed considering the possibility of transferring the solutions from one tank to another by special vacuum pumps, the intake capacity of which is no more than 7 meters for liquid waste density of 1 ton/$m^3$ and less than 7 meters for higher density. Accordingly, the height of the storage tanks is limited.

The volume of each group of tanks (for concentrated solutions, slurries, spent resins and sorbents) and the total capacity of the storage pits are determined by the following arguments: the amount of waste of each type, the time in which filling of the tanks is calculated, the proposed storage time of the waste (long-term or temporary storage considering transfer of the waste after reduction of activity to cheaper tanks), the possibility of using viable components contained in the waste, the half-life of the isotopes contained in the waste, physical and chemical changes in the process of storing this waste, the required reserve (in established practice one additional tank is provided as the reserve in case of emergency), and so on. Some of the problems of optimizing the liquid radioactive waste storage pits are discussed in [28].

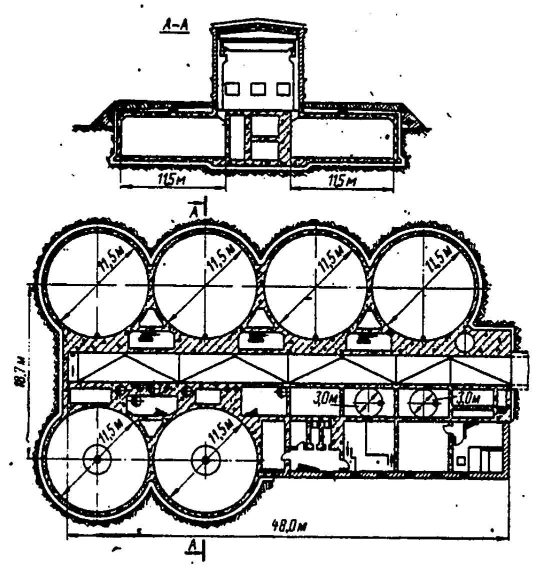


Figure 1-21. Storage pit for liquid radioactive waste with 2,400 $m^3$ capacity.

As an example, the space planning of a standard liquid waste storage pit with capacity of 2,400 $m^3$ is presented in Figure 1-21. It is necessary to set up inspection pits to monitor possible leaks around the storage pits of nuclear power plants.

One of the prospective methods of solidifying the liquid waste from nuclear power plants must be considered to be the bituminization method. The bituminized blocks with a specific activity to 1 curie/liter can be stored in concrete boxes without waterproofing.

The solid waste is sorted before storage with respect to contamination level, and it is placed in the burial pit consisting of individual boxes for storing waste of different activity. Usually the waste is transported in special trucks or battery-operated vehicles equipped with shielding. The set of structures of the solid waste storage pits includes the following: a facility for collection, temporary storage and conversion of flammable and explosive radioactive waste material to a harmless state, a facility for deactivation of the special motor transportation, containers and equipment, storage for the rotating containers, a garage for the special vehicles, tanks for burying the waste by contamination groups.

The burial of low-active solid waste is permitted in closed-type trenches with low groundwater levels in argillaceous soils. The trenches must be far from the water intakes and open water areas.

The solid waste of medium activity is buried in concrete burial pits, and highly active, in underground waterproofed tanks.

For storing the combustible solid waste, separate tanks are provided. Special safety measures are taken to prevent spontaneous combustion of the waste, and special ventilation is installed. The propagation of the radioactivity around the solid waste storage pits is monitored by using inspection pits around the perimeter of the storage pit 10-15 meters away.

# CHAPTER 2. CHOICE OF CONSTRUCTION SITES AND MASTER PLANS FOR NUCLEAR POWER PLANTS

## 2-1. Special Features of Nuclear Power Plants and Construction Site Requirements

With an increase in the number of nuclear power plants, the choice of the site for their construction is becoming more and more complicated. The most optimal version of the siting of a nuclear power plant which insures minimum expenditures when building the plant and maximum convenience when operating it is selected on the basis of analyzing all of the investigated versions of the sites. For this purpose it is necessary to make a careful study of the local conditions and to know the construction and operating characteristics of nuclear power plants thoroughly as a function of their specific location.

When selecting the site for nuclear power plants it is ncessary clearly to represent an entire complex of structures forming the nuclear power plant, their functional purpose and the possibilities of the arrangement of one structure relative to another. When choosing the site for building a nuclear power plant problems of its relationship to the outside world during construction and operation must be taken into account.

Establishment of the necessity for building a nuclear power plant in a given region from the condition of an electric power shortage and the plan for the development of the power system, determination of the possibility of building the nuclear power plant beginning with insuring operating safety, satisfaction of the sanitary norms, meeting the requirements for water to cool the turbounits, admissibility of using the planned construction site in connection with long range plans for building other enterprises and environmental protection, finding the most economical version of building the nuclear power plant based on analyzing the entire set of construction and operating problems -- these are the large-scale, complicated problems which face the specialists in charge of choosing the site for the nuclear power plant.

Errors in selecting the construction site for a nuclear power plant can lead to cost overruns of tens of millions of rubles.

The necessity for building a nuclear power plant, just as any new electric power plant, is established as a function of the plans for development of the national economy and an increase in the power users in the given area. A predicted shortage of electric power in an investigated region determines the final power of the electric power plant and the introduction of the power, correspondingly, by years to meet the electric power demand [34].

When choosing the type of electric power plant, the peculiarities of nuclear power plants are taken into account. From the point of view of siting, nuclear power plants have greater mobility than thermal or hydroelectric power plants. They are not rigidly tied to rivers with high energy potential, such as hydroelectric power plants, and they do not need a continuous supply of fuel in connection with the fact that the fuel consumption is comparatively smaller than that of thermal electric power plants. Thus, for the operation of a modern coal-fired electric power plant of 1 million kilowatts it takes about 8000 tons of coal a day. For continuous operation of such a plant for a year it is necessary to haul in about 60,000 50-ton cars of coal. For the operation of a nuclear power plant of the same power the annual uranium fuel requirement is only about 50 tons.

In the power system the nuclear power plants function primarily in the base part of the load chart. This arises from the peculiarities of the cost structure of electric power generated at a nuclear power plant.

Since at nuclear power plants the fuel component is a lower part of the cost of electric power than at thermoelectric power plants operating on organic fuel, it is naturally advantageous to insure maximum generation by the nuclear power plant. The efficiency of the use of the installed capacity of the power plant is characterized by the use coefficient which reflects the operating time of the electric power plant with maximum possible power for the investigated time interval. The use coefficient $K_{use}$ depends on the quality of the equipment and operation of the power plant and the loading of the nuclear power plant in the power system:

$$K_{use} = (Q_{act}/Q_{poss})\ 100\%, \tag{2-1}$$

where $Q_{act}$ is the actually generated amount of electric power in the investigated time interval (month, quarter, year); $Q_{poss}$ is the possible amount of electric power which the plant could put into the system during operation for the entire investigated time interval at 100% of the installed capacity.

One of the possible versions when estimating the possibility of building a nuclear power plant is insurance of the safety of its operation for the surrounding population which is regulated by the radiation safety standards. In the USSR radiation safety norms are in effect [59] which reflect the recommendations of the International Committee on Radiation Safety (ICRS) and the International Atomic Power Agency (IAPA). According to these norms the maximum admissible releases of radioactive materials into the atmosphere and open bodies of water are determined beginning with the fact that irradiation of man caused by the operation of a nuclear power plant must not differ significantly from the irradiation from the natural radioactive background.

In connection with large-scale plans for the development of nuclear power engineering, the growth of the number and total power of the nuclear power plants it is necessary continuously to achieve a decrease in radioactive discharge into the environment during normal operation of the nuclear power plant and a reduction in the probability of such discharges in case of emergency. This is necessary in order that the total discharge from all nuclear power plants in operation considering the probability of emergencies will not exceed the limit alloted to the nuclear power plant in the overall irradiation of the population not leading to harmful consequences. It is necessary to limit irradiation of the entire population in every possible way by decreasing the dosage obtained by individual people and as a result of limiting the number of people subjected to irradiation.

One of the environmental protection measures, including both territory and population to be protected against harmful effects of the operation of nuclear power plants is the organization of a sanitary safety zone around it.

When choosing the construction site for a nuclear power plant consideration must be given to the possibility of creating the sanitary safety zone defined by a circle the center of which is the vent pipe of the nuclear power plant. At the present time in the sanitary requirements the size of the sanitary zone has not been delimited [77]; it is established in each specific case by agreement with the agencies of the government sanitary inspectorate as a function of the type and power of the reactor, the calculated amount of radioactive discharge, climatic, meteorologic, and topographic conditions in the vicinity of the nuclear power plant site, considering the proposed (ground level) concentrations of radioactive materials and gamma radiation caused by the discharge. The annual dosage of irradiation of the population living in the vicinity of a nuclear power plant must not exceed 0.17 rem per year.

If the monitoring of the radiation situation during operation of the nuclear power plant demonstrates that the actual discharge exceeds the calculated discharge, the dimensions of the sanitary safety zone can be increased.

It is forbidden that the population live in the sanitary safety zone, but buildings and structures for subsidiary purposes, fire houses, garages, warehouses (except for produce), dining rooms for the service personnel of the nuclear power plant, and so on are permitted to be located there. The territory of the sanitary safety zone can be used for growing agricultural crops and pasturing livestock with the mandatory condition of dosimetric monitoring of the territory and the farm products growing there by the external dosimetry service of the nuclear power plant.

Special attention must be given to investigation of wind conditions in the vicinity of the construction site in order to locate the nuclear power plant downwind from the populated areas.

Beginning with the possibility of emergency leakage of active fluids preference is given to sites with deep ground water levels. The highest level of such water must be no less than 1.5 meters below the floor level of the planned underground structures of the nuclear power plant in which the presence of radioactive fluids is possible.

When selecting the site for building a nuclear power plant the service water supply has great significance [22, 60]. A nuclear power plant is a large water user. The water consumption of the nuclear power plant is insignificant, and the use of water is high, that is, basically the water is returned to the water supply source. An enormous amount of water is required to condense the spent steam of the turbines. In addition, service water is used to cool other equipment of the nuclear power plant, to make up water losses from the closed circuits, to provide for the drinking water needs of the electric power plant personnel and the residents of the settlement.

The expenditures on the water supply of a powerful nuclear power plant are reckoned in millions of rubles, and all possible versions of the service water supply of a nuclear power plant must be carefully substantiated technically and economically when selecting the site. When selecting the water supply system it is necessary to make maximum use of natural water areas, strive to limit the construction of new hydroengineering complexes, long canals and artificial hydroengineering structures.

Environmental protection requirements are imposed on nuclear power plants, just as on all industrial structures in the construction phase. The use of a large amount of water at nuclear power plants for service needs leads to the possibility of increased water losses in the water supply sources by comparison with natural conditions. In order to prevent inadmissible lowering of the water level in rivers and reservoirs as a result of irrecoverable losses of water used in the operation of nuclear power plants to evaporation and leakage into the ground, these losses are limited as a function of the specific conditions of the siting of the power plant. Beginning with these conditions an analysis must be made of the possibility of building the power plant and defining its final power.

The standards regulate the conditions of intake and discharge of water at nuclear power plants so as not to exceed the maximum permissible heating of the water in open bodies of water having national economic significance. In order to protect the plant and animal world, the water temperature in the bodies of water must not rise by more than 3-5° C depending on the time of year. For observation of this condition it is necessary that the water consumption in a river exceeds by no less than threefold the flow rate of discharged cooling water during the calculated period [67]. At this time a study is being made of the possibility of using heat discharged from nuclear power plants for thermal irrigation, the breeding of fish and the creation of agroindustrial complexes based on electric power plants.

When choosing the site for construction of a nuclear power plant it is necessary to be guided by the following requirements:

The ground set aside to build the nuclear power plant is unsuitable or has low suitability for agricultural purposes;

The construction site is located on bodies of water and rivers, in coastal regions which will not be inundated by flood waters (considering the lowest lift height of the cooling water);

The soil of the site permits construction of buildings and structures without additional expensive measures;

The ground water level is below the depth of occurrence of the basements of buildings and underground engineering service lines and no additional expenditures are required on lowering the water when building the nuclear power plant;

The site has relatively level surface with a slope providing for surface runoff of the water; the earthwork will be reduced to a minimum in this case.

In the case of a departure from these requirements when comparing the versions of the proposed nuclear power plant construction sites a careful technical-economic analysis must be made that takes into account additional expenditures caused by unfavorable conditions of the construction site.

The construction of nuclear power plants is not recommended in seismic zones in the presence of flooded soft ground (unstable sandy loams, unstable clayey loams and clays, ooze and peaty soils, backfill, and so on). If the necessity for building the nuclear power plant buildings and structures under these conditions is substantiated, it is necessary to take additional measures to reinforce the foundations or replace the soft ground. Sites within the boundaries of which or in the direct proximity to which seismic fractures or faults have occurred should not be used for building nuclear power plants [74].

As a rule, it is forbidden to build nuclear power plants:

In active karst zones;

In areas with serious (massive) avalanches and mud flows;

In areas with possible snow avalanches;

In swampy and superwet areas with constant inflow of rising ground water. The extreme necessity for locating a nuclear power plant in such a region must be confirmed by a technical-economic analysis, and the additional expenditures for building and operating the nuclear power plant with elimination of the unfavorable conditions must be defined;

In large-scale downwarp zones caused by mining;

In the primary and secondary belts of the sanitary safety zones of kurorts [health resorts] and water supply sources;

In sections contaminated with organic and radioactive waste before the expiration of the times established by the USSR State Sanitary Inspectorate;

In areas of occurrence of minerals without agreement with the Gostortekhnadzor agencies;

In a possible zone of flooding from rupture of dams located above the proposed electric power plant construction site;

In regions subject to the effect of disastrous phenomena such as tsunami, and so on.

The level of the nuclear power plant site must not be less than 0.5 meters above the calculated high water level of bodies of water or rivers considering backwater and slope of the stream and also the wave height and incursion. The highest water level caculating the probability of repetition once in 10,000 years, that is, with a calculated guarantee of 0.01%.

## 2-2. Engineering Surveys

In order to determine the possibility of building nuclear power plants in planned areas and for comparison of the versions with respect to geological, topographic and hydrometeorological conditions in the site selection phase, specific studies are made with respect to investigated versions of siting the power plant [33, 60].

The engineering-geological surveys are performed in two steps. In the first step materials are gathered on previously performed surveys in the investigated region, and the degree to which the proposed construction site has been studied is determined. In the second step, if necessary, special engineering-geological surveys are made, boring holes and taking soil samples, and also geological reconnaissance studies are made of the site. By the results of office processing of the gathered data and additional studies, an engineering-geological description of the construction area is obtained which defines the relief and the geomorphology of the territory, the stratigraphy, the thickness and lithologic composition of the basement and Quaternary deposits in the region to a depth of 50-100 meters, the number, the nature, and the level of occurrence and conditions of propagation of individual aquifers within the boundaries of the overall depth (for the first aquifer from the surface, it is mandatory to obtain the annual amplitude of the level fluctuations), the nature and intensity of the physical-geological processes and phenomena (avalanches, karst, erosion, marshiness, gully formation, and so on).

When performing the engineering-geological surveys in the site selection phase information is gathered on the presence of local building materials -- workable rock, sand and gravel pits, quarries and deposits, and other sources of building materials.

In the same period possibilities are determined for using the groundwater for production and general services-potable water.

The cartographic materials and the plan height of the geodetic base of the site are obtained as a result of the topographic-geodetic surveys. In the first phase of these surveys the available cartographic material on the proposed nuclear power plant construction site are gathered and analyzed. The outlines of the site are planned on the basis of this study, the profiles of the transverse cross section of a river valley or water area are compiled, the plants at which the access routes are adjacent to existing roads and railroads are noted, and possible routes for electric power transmission lines are defined.

For determination of the sanitary-safety zone data are gathered on the populated areas and the construction in the vicinity of the proposed nuclear power plant with application of the number of residents, the number of buildings and types of structures and also the areas of cultivated ground with indication of the type of crops and forested areas. The distances to the nearest large population centers are determined.

In estimating the overall situation in the vicinity of the construction site, 1:100,000 and 1:50,000 scale maps are used; for more detailed analysis in the site selection phase, maps are needed with a scale of no less than 1:25,000 or 1:10,000 with horizontals every 2-5 meters. In the absence of 1:25,000 scale maps and larger, the site is surveyed and represented on a 1:25,000 scale with horizontal sections of the relief altitude every 5 meters.

When selecting a nuclear power plant site, hydrologic surveys are made to evaluate the water reserves, choose the water supply source and the part of the river suitable for water intake and for preliminary planning of the water supply system.

In the first phase of these operations all of the available published data, the observation data of the stationary hydrometeorological network, the data on the water management of the river and the operating conditions of existing hydroengineering structures are gathered and analyzed. In the second phase of the operations, after analyzing the gathered data, a program of engineering-hydrologic investigation is defined, as a result of which the missing data is obtained. From the hydrologic surveys, a stream description is obtained which contains the following data: water level characteristics (maximum, minimum, and so on) and information about ice conditions, the water flow curve, the annual total, the norms, variability, the water flows with different guarantees, seasonal (monthly) runoff distribution in years that are characteristic with respect to water supply, minimum runoff, maximum (calculated) flow rates of the water, chemical composition of the water, pollution and other information about water quality.

The meteorological characteristics of the regions are established during the site selection phase by the data from the existing meteorological stations and official climatic references.

When selecting a nuclear power plant site, special attention must be given to determining the seismicity and a careful study of seismic activity [39, 43, 44] of the proposed region in which the nuclear power plant is to built and the microseismicity of the plot directly set aside for siting the power plant. This is especially important when selecting the building site for the nuclear power plants, for nuclear power plants are still not being built in regions with seismicity of more than 9.

The requirements with respect to seismic stability imposed on the structures and equipment of nuclear power plants are much more rigid than for ordinary responsible industrial structures.

The seismic activity of the region of construction of nuclear power plants is considered beginning with four on the Mercalli Cancani scale which was used as the basis for the system of estimating earthquake activity in our country. The necessity for considering earthquakes beginning with four and not with six as SNiP require for ordinary structures arises from the increased requirements on preserving the equipment and the pipelines of the radioactive circuit of the nuclear power plant and systems insuring radiation safety of the plant.

When determining the calculated seismicity of the nuclear power plant construction site it is necessary to consider that the seismicity of the region presented on the seismic regionalization maps is established for sections with medium soil conditions -- sandy-clayey soils with low groundwater level.

For a specific building site it is necessary more precisely to define the seismicity in accordance with the actual soil conditions by the engineering-geological and hydrologic survey data. Gravelly, sandy and clayey (macroporous) soils saturated water and also plastic and unstable argillaceous soils are unsuitable for construction under seismic conditions, and the calculated seismic rating must be increased for them.

The nuclear power plant structures and equipment are designed for the maximum possible predictable seismic activity in the given region. In the practice of designing nuclear power plant structures for seismic effects in Japan and the United States the accelerations in the case of maximum possible earthquakes are taken twice as large as for the maximum recorded earthquakes, that is, for especially responsible structures of the nuclear power plant the calculated accelerations are doubled as compared to the calculated forces from the seismic effects for ordinary buildings in the given region.

In the USSR the possible seismicity of the region with a probability of once every 10,000 years is considered in calculating the seismic effects on the structures in which the systems guaranteeing radiation safety of the nuclear power plant are located.

The importance of proper evaluation of the calculated forces from earthquakes for all of the electric power plant elements without exception is explained by the fact that the earthquake has a simultaneous effect on all systems and structures guaranteeing the safety of the nuclear power plant, and in case of failure of even one responsible link in this complex, expensive chain the safety of the nuclear power plant can be violated.

## 2-3. Master Plan

When designing nuclear power plants, just as other large industrial complexes, construction site plans, master plan diagrams and master plans for the industrial site of the nuclear power plant are created.

In order to obtain the general idea of the power plant construction site, a site plan is drawn up (Figure 2-1) usually on a 1:10,000 scale on which the location of the industrial site, the construction base, the housing and other structures are indicated. The connections of roads and railroads to the government main lines are depicted on the plan, and the boundaries of the sanitary zone are plotted.

In the early phases of the design work -- in the technical-economic substantiation and when selecting the building site — a general master plan is put together showing the layout of the nuclear power plant structures and their mutual coordination on the building site, on which the main structures of the nuclear power plant and their proposed locations are given without plan and altitude coordination. The master plan diagrams are also made in later design phases, in the contract and detailed design phase, as illustrative, demonstration material. Examples of master plan diagrams are presented in Figures 2-2 to 2-6 for various projects.

The master plan developed in the contract design phase defines the specific placement of the nuclear power plant building structures on the industrial site in plan with indication of their dimensions also with respect to altitude. On the master plan all of the electric power plant structures are tied to the structural net (Figure 2-7), that is, the coordinates are indicated for each of them. The structural net is a provisional orthogonal system of lines forming squares with spacing of 100 meters as a rule. The structural net usually is indicated by the letter B on the horizontal and the letter A on the vertical.

The master plan drawings are basically executed at 1:1000 scale. The following are indicated on them:

The coordinate grid in the structureal coordinate system;

The topographic true basis in sections where there are no provisions for organizing the relief by leveling;

Datum marks, prospecting pits, bore holes and reference symbols of the structural net;

Grading and water drainage elements (banks, retaining walls, steps, gutters, catch basins, and so on);

The buildings and structures, including the service line structures (tunnels, trestles, galleries), production and storage areas;

Roads and paved areas, passages through the planned territory;

Railroads, transformer tracks, crane tracks;

Open service water supply canals;

Electric power transmission line outlets;

Enclosure of the territory of the industrial site and the sites of individual structures.

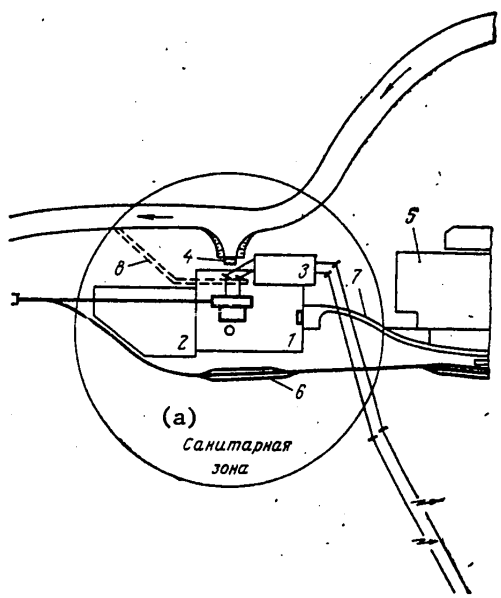


Figure 2-1. Example site plan of a nuclear power plant. 1 -- industrial site; 2 -- construction base; 3 -- open switch gear; 4 -- service water supply pumping station; 5 -- housing; 6 -- railroad station; 7 -- access road; 8 -- drainage canal.

Key: a. decontamination zone

When developing master plans it is necessary to consider the possibility of the development of the nuclear power plant to its final power, for which areas are provided for subsequent expansion of the plant and, beginning with this condition, individual power plant structures are sited in plan. Usually the rules of not building auxiliary structures in the direction of possible expansion of the main facility are adhered to.

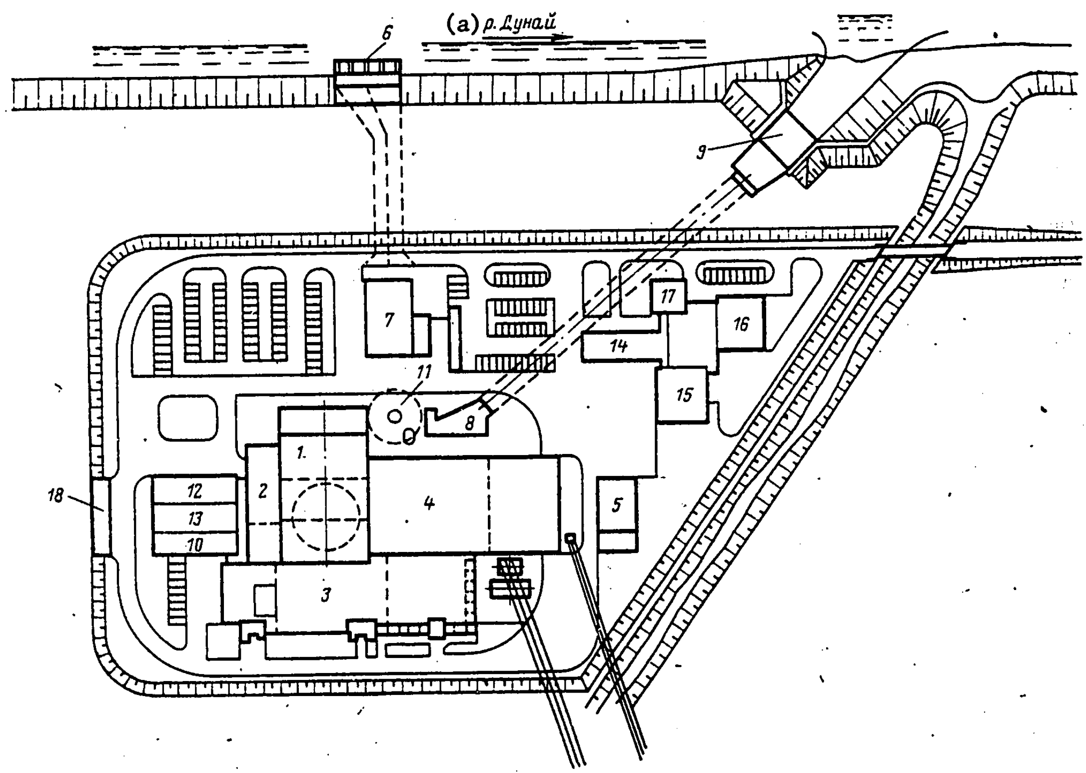


Figure 2-2. Master plan diagram of the Tulnerfeld nuclear power plant with BWR (Austria). 1 -- reactor section and auxiliary installation complex; 2 -- deactivation facility; 3 -- distribution station; 4 -- machine room; 5 -- emergency diesel engine building; 6 -- water intake structures; 7 -- service water pumping station; 8 -- spent fuel element holding pool; 9 -- water drainage structures; 10 -- water treatment structure; 11 -- vent pipe; 12 -- workshop; 13 -- storage area; 14 -- security; 15 -- diningroom; 16 -- administrative building; 17 -- information building; 18 -- garages.

Key: a. Danube River

When developing the master plan the proper choice of the routine for roads and railroads within the industrial site and efficient joining of them to the public rightaways has great significance. It is necessary that each building have convenient accesses and approaches and at the same time that the areas occupied by the roads and railroads be minimized. The railroad routes must be especially carefully developed, for the standards of the Ministry of Railways with respect to permissible grades and turning radii lead to great complications when laying out the master plans.

The master plans must be developed in accordance with the requirements of the construction norms and rules, the sanitary norms with respect to designing nuclear power plants and the norms for the engineering design of thermoelectric power plants.

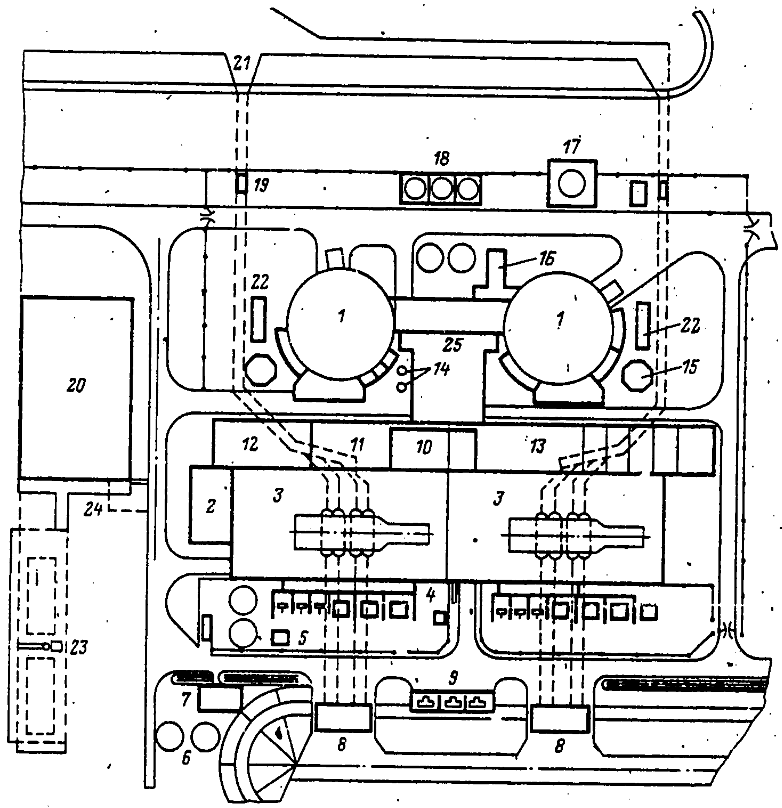


Figure 2-3. Master plan diagram of the Surrey nuclear power plant with water-cooled, water-moderated power reactors (United States). 1 -- reactor envelope; 2 -- administration building; 3 -- machine room; 4 -- fresh air intake; 5 -- transformer for general plant in-house needs; 6 -- water storage tanks; 7 -- fire pumping stations; 8 -- water intake structures; 9 -- reserve transformers; 10 -- control panels; 11 -- work shop; 12 -- storage area; 13 -- laboratories, decontamination station; 14 -- tanks; 15 -- fresh fuel storage; 16 -- special purification building; 17 -- fuel oil storage tanks; 18 -- primary water storage tanks; 19 -- drainage canal; 20 -- automobile parking; 21 -- drainage; 22 -- condensate tank; 23 -- sewage settling tank; 24 -- temporary substation; 25 -- auxiliary building.

Comprehensive reduction of the ground condemned for construction of the nuclear power plant is the primary goal in the design work. The analysis of the condemned area of existing nuclear power plants and those under construction indicates that the greatest proportion goes to the cooling ponds (if a water supply of this type is used), and then for housing, the construction-installation base and, finally, the industrial site of the nuclear power plant.

The best indexes on the master plan are achieved when designing the nuclear power plant directly for total power with compact arrangement of the structures in the relief, maximum blocking of the buildings and structures of the nuclear power plant

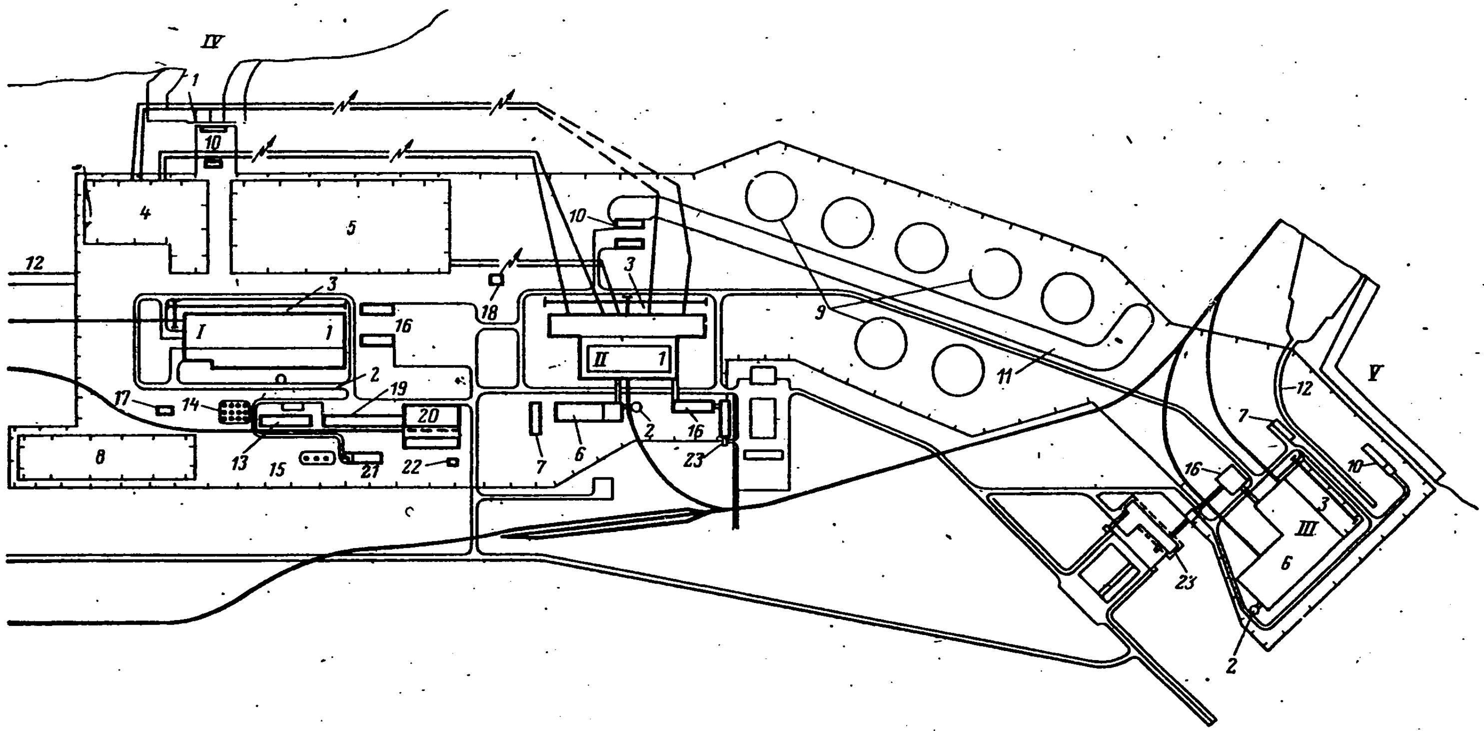


Figure 2-4. Master plan diagram of a nuclear power plant. 1 -- main facility; 2 -- vent pipe; 3 -- open transformer installation; 4 -- 220 kilovolt outdoor distribution station; 5 -- 500 kilovolt outdoor distribution station; 6 -- special service building; 7 -- diesel generator plant; 8 -- liquid and solid waste storages; 9 -- cooling towers; 10 -- service water supply pumping stations; 11 -- feed channel; 12 -- discharge channel; 13 -- chemical water purification; 14 -- oil station; 15 -- fuel oil station; 16 -- engineering, administrative and general services building; 17 -- nitrogen-oxygen station; 18 -- dining room; 19 -- workshops; 20 -- warehousing; 21 -- starting boiler room; 22 -- acetylene generator plant; 23 -- service facility; I -- first and second power units; II -- third and fourth power units of the nuclear power plant; III -- fifth power unit of the nuclear power plant; IV -- river; V -- reservoir.

and reduction of auxiliary structures by using outside services, centralized supply with the required components for operation and maintenance: oxygen, acetylene, and so on.

The volume of earthwork performed when grading the industrial site for the nuclear power plant and organizing access routes must be minimized. If the slope of the natural relief of the construction site exceeds 0.03, usually terracing of the power plant site is used. This type of grading is also recommended when locating nuclear power plants on rocky ground in order to reduce the expensive operations of moving rock. Economicalness of terracing is estimated with respect to the overall complex of operations of building the power plant considering, if necessary, possible changes in the expenses of operating and maintaining it.

The location of the construction base is indicated on the site plan for the nuclear power plant construction zone. A construction master plan is developed as part of the contract design on which the locations of the assembly areas, the production-auxiliary and administrative and general services buildings of the construction base, communications and service lines, and so on are indicated.

The set of temporary structures which must be built is determined considering the possibility of using permanent auxiliary service buildings of the nuclear power plant during the construction period.

The nuclear power plant complex includes the basic production building structures and subsidiary production and auxiliary building structures.

The basic production buildings and structures include the following:

The reactor section in which the reactor and its service systems are located;

The machine room in which the turbogenerator, the high and low pressure heater systems, deaerators, and so on are located;

Electrical year high-rise annexes with control panels, cable distribution installations, and so on;

The special service building which includes the systems for special cleaning of the radioactive circuit and the liquid and solid radioactive waste storages;

The diesel generator plant where the reliable power plants -- diesel generators -- are installed;

Hydroengineering structures supplying the nuclear power plant with water: pumping stations, cooling towers, canals, and so on.

The subsidiary production and auxiliary building structures include the following:

The sanitation and general services building in which the sanitation and general services are located with a special laundry;

Acetylene-generator plant;

Electrolysis;

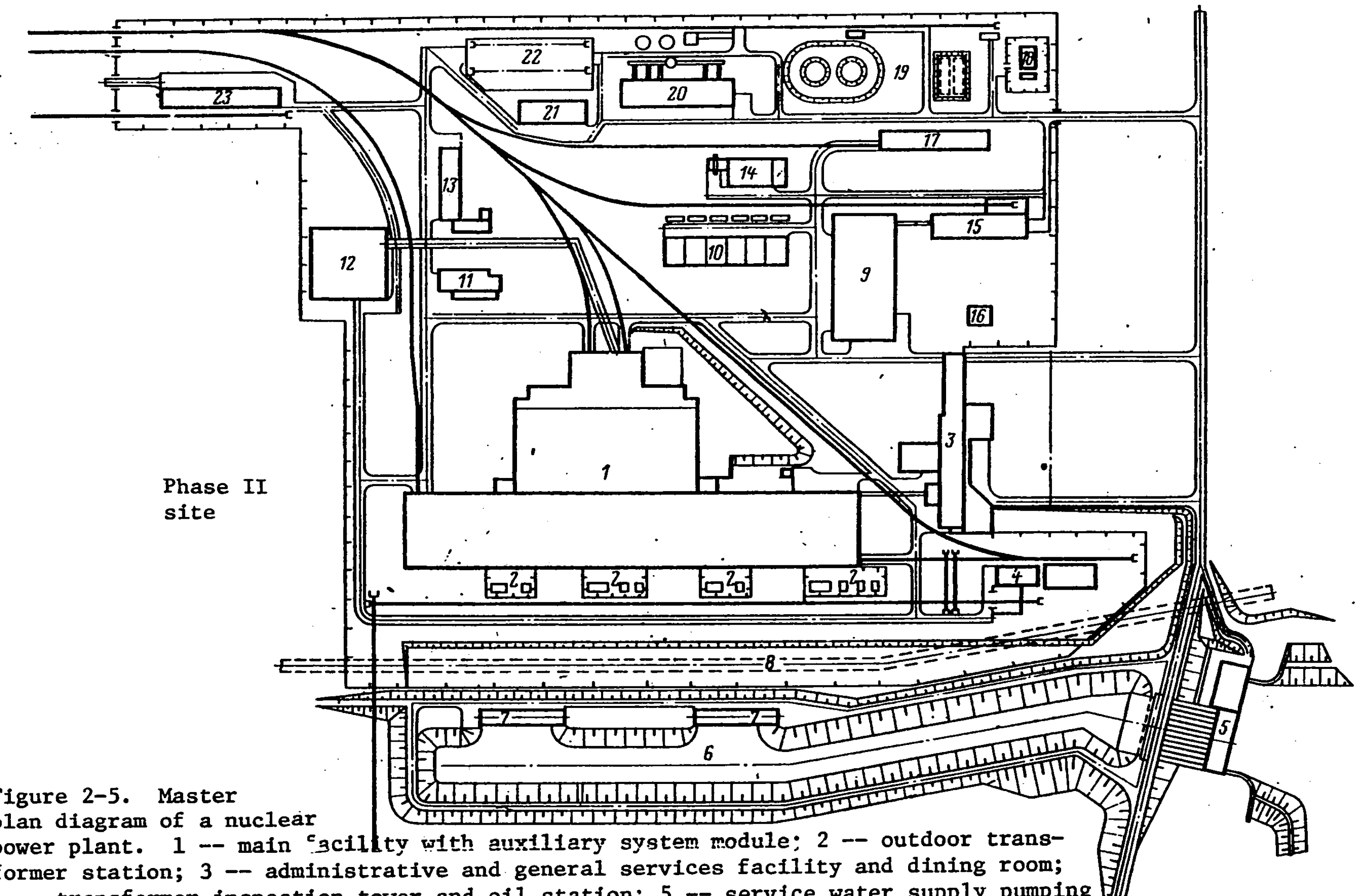


Figure 2-5. Master plan diagram of a nuclear power plant. 1 -- main facility with auxiliary system module; 2 -- outdoor transformer station; 3 -- administrative and general services facility and dining room; 4 -- transformer inspection tower and oil station; 5 -- service water supply pumping station; 6 -- supply channel -- delivery basin; 7 -- water intake structures; 8 -- discharge channel; 9 -- united auxiliary facility; 10 -- diesel generator plant; 11 -- compressor station; 12 -- liquid and solid waste storage; 13 -- nitrogen-oxygen station; 14 -- repair and construction shop ; 15 -- chemical reagent storage area; 16 -- hydrogen receivers; 17 -- fresh fuel storage area; 18 -- acetylene generator plant ; 19 -- fuel storage for the boiler room; 20 -- reserve boiler room; 21 -- serpentinite storage; 22 -- equipment area; 23 -- graphite storage.

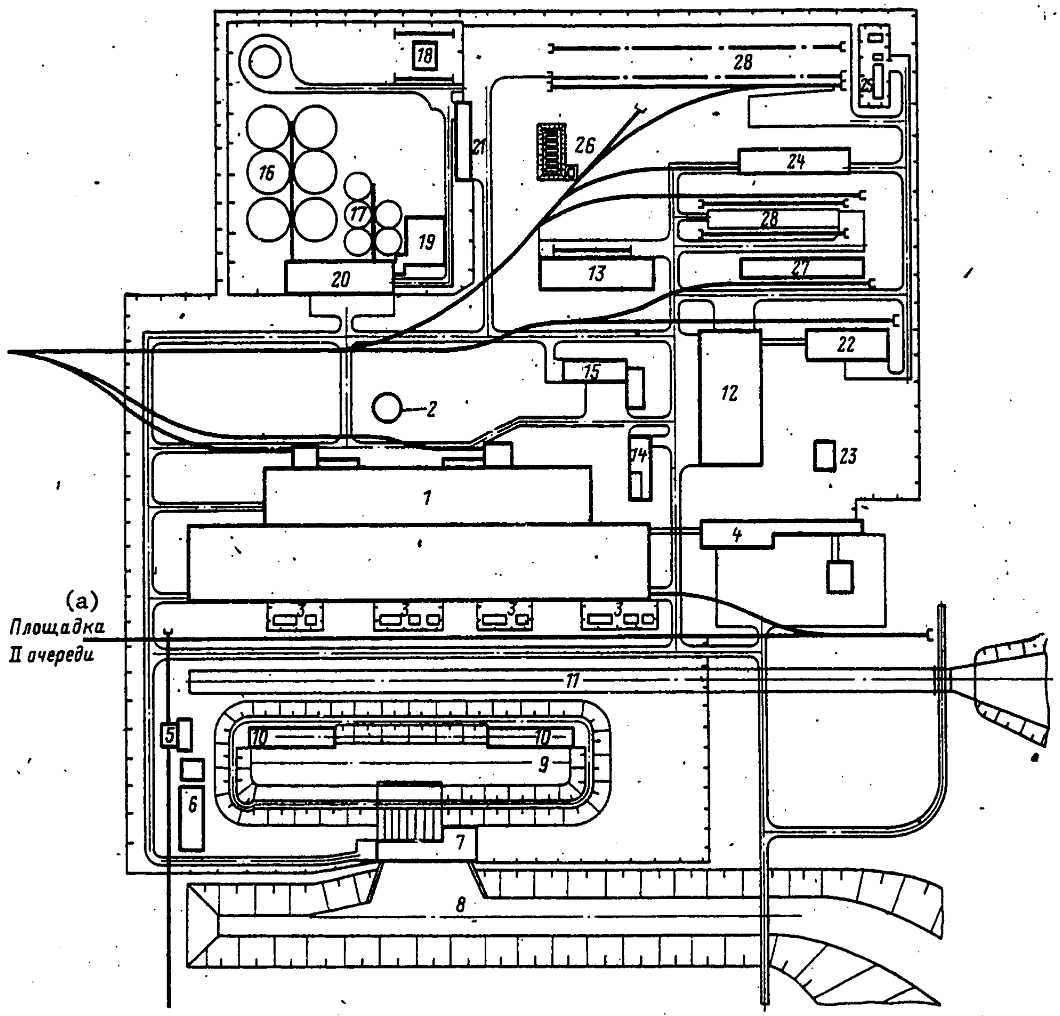


Figure 2-6. Master plan diagram of a nuclear power plant. 1 -- main facility; 2 -- vent pipe; 3 -- open transformer installation; 4 -- administrative and general services building and dining room; 5 -- transformer inspection tower; 6 -- oil station; 7 -- service water supply pumping station; 8 -- supply channel; 9 -- delivery basin; 10 -- water intake structures; 11 -- discharge channel; 12 -- combined auxiliary facility; 13 -- diesel generator plant; 14 -- compressor station; 15 -- nitrogen-oxygen station; 16 -- liquid waste storage; 17 -- wastewater tank; 18 -- solid waste storage; 19 -- gas folding chambers (UPAK); 20 -- discharge water treatment facility; 21 -- garage and washing of transport systems; 22 -- chemical reagents storage; 23 -- hydrogen receivers; 24 -- fresh fuel storage; 25 -- acetylene generator plant; 26 -- diesel fuel storage; 27 -- graphite storage; 28 -- open area with gantry cranes.

Key: a. phase II site

Nitrogen-oxygen station;

Material storage, and so on;

Administrative services.

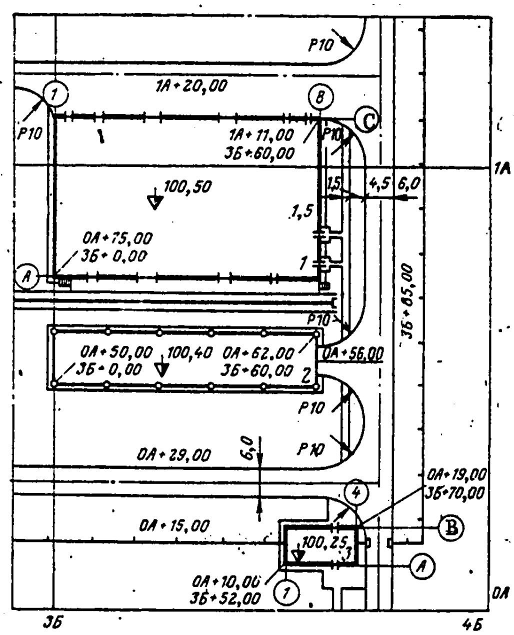

Figure 2-7. Example of gridding the structures on the master plan.
1 -- combined auxiliary facility; 2 -- materials storage (shed);
3 -- approach route.

The nuclear power plant structures must be located beginning with the process engineering relation of the auxiliary services to the basic production, placing the services as close as possible, observation of sanitation, fire safety and other norms at the same time which establish the minimum allowable distances between the various production buildings.

In order to reduce the covered area and the length of the service lines, maximum blocking of the building structures by functional purpose is used.

An example of the itemized list of some of the structures of nuclear power plants with the VVER-440 water-cooled, water-moderated power reactors is presented in Table 2-1. The itemized list of hydroengineering structures is not included.

The layout of the hydroengineering structures is determined by the selected service water supply system. The carrying capacity of the service water supply structures usually is adopted for the total power of the plant considering its possible expansion.

Table 2-1. Descriptions of some of the structures of nuclear power plants with two VVER-440 reactors

| Structures | Covered area, $m^2$ | Building space, $m^3$ |
|---|---|---|
| Main facility: | 19,440 | 627,310 |
| machine room: | 9,700 | 323,865 |
| above ground section | | 288,500 |
| underground section | | 35,465 |
| electrical equipment stacks: | 3,150 | 86,470 |
| above ground section | | 75,930 |
| underground section | | 10,540 |
| reactor division: | 4,950 | 184,395 |
| above ground section | | 174,755 |
| underground section | | 9,640 |
| ventilation center: | 1,640 | 32,580 |
| above ground section | | 28,400 |
| underground section | | 4,180 |
| Special service building: | 3,780 | 42,280 |
| above ground section | | 36,610 |
| underground section | | 5,670 |
| Vent pipe | | |
| Trestles between the ventilation center, auxiliary facility and vent pipe | 54 meters long | |
| Sanitation-general services and laboratory facility and crosswalk | 1,385 | 27,895 |
| above ground section | | 26,200 |
| underground section | | 1,695 |
| Nitrogen station | 240 | 1,800 |
| Diesel generator plant | 570 | 6,750 |
| Outdoor transformer installation | 980 | |
| Underground tunnels and corridors | | |
| Desalinated water tanks, boron solution and condensate reserve | | |

As an example it is possible to consider the service water supply of the Novovoronezh Nuclear Power Plant at which various water cooling systems were used. It must be noted that the Novovoronezh nuclear power plant was a type of test area for industrial testing of pilot power units with water-cooled, water-moderated power reactors. Three power plants with different main facilities were in practice built at the Novovoronezh power plant site.

In the first two power units with a total power of 560 megawatts in which eight K-70-29 turbounits were installed, the through-flow water supply system is used. Pumps installed in the pumping station on the banks of the Don River pumped the water from the Don to the turbine condensers through the pressurized circulating water lines. From the turbine condensers the warm water flows by gravity through a reinforced concrete discharge channel that is enclosed in the power plant area, and the water is discharged downstream.

In the third and fourth power units with two VVER-440 reactors and four K-220-44 turbounits, the circulating water supply system with cooling towers is used. Seven cooling towers have been installed for the two power units.

The water that is cooled in the cooling towers is directed through an open canal to the circulating pumping station from which it is delivered to the turbine condensers. The warm water from the turbine condensers is lifted to the cooling towers. Flowing down through the louvered slate trickles, the warm water is cooled and flows by gravity through an open canal to the circulating pumping station. A closed circulating cooling system circuit is obtained: cooling towers, canal, circulating pumps, turbine condensers, cooling towers.

As a result of the enormous flow rates of the water required to cool the turbines, the dimensions of all of the structures of the service water supply system are significant: the hyperbolic cooling towers are 90 meters high and 90 meters in diameter at the bottom; the supply channel is 5 meters deep and 30 meters wide at the top; for the pressurized circulating water lines, metal pipe up to 3 meters in diameter is used.

For the fifth power unit of the 1000 kilowatt Novovoronezh nuclear power plant with three K-1000-60 turbounits, a circulating service water supply system with cooling pond was adopted. The cooling pond was organized by building earthen dams in the floodplain of the Don. In order not to allow the warm water from the discharge channel to enter the water intake of the pumping station directly, a separating earthen dam was built in the reservoir which lengthens the path of the warm water and insures that it is mixed with cold water, involving all of the reservoir water in active cooling.

# CHAPTER 3. FLOOR SPACE DESIGNS OF NUCLEAR POWER PLANT BUILDINGS

## 3-1. Requirements on the Layouts of the Facilities

The goal when designing nuclear power plants is the creation of the most efficient (optimal) design. For this purpose it is necessary to discover functional (process) factors, determine their influence on the shaping of all the facilities and buildings of the nuclear power plants and also to formalize the design process for use of computers and modern mathematical methods.

The basic requirements to which the nuclear power plant buildings must correspond are as follows:

Convenience for performance of the basic technological process for which they are designed (functional expediency of the building);

The reliability under environmental effects, strength and service life (technical expediency of the building);

Aesthetics (architectural-artistic expediency);

Economicalness, not at the expense of service life (economic expediency).

The layout of a nuclear power plant is created by a collective of designers of different specialties. The layout of the nuclear power plant is made up of the following processes:

1. In the design assignment, the type and power of the nuclear power plant is defined, in accordance with which the basic equipment of the power plant is selected.

2. The overall dimensions of the basic equipment are determined by the plant studies, and the cells for siting in plan and with respect to altitude are determined in accordance with the modular spacing for the structural component.

3. The layout of the structures at the nuclear power plant is planned, and approximate siting of them is done on the master plan.

4. The services to be placed in each structure and communications between them are determined, and the dimensions of the facilities for these services are approximately noted. This is the most responsible period, for the theoretical distribution of the building volumes determines the effectiveness of the layout. In this period:

The process engineers arrange the production equipment in accordance with the selected flow chart, and they plan the theoretical layouts of the reactor section, machine room and special water purification;

The electricians site the electrotechnical equipment, layout the cables and theoretically layout the stack of electrical devices and plan the locations of the cable flows;

The specialists in monitoring and measuring instruments and process automation site the monitoring and measuring instrument equipment and organize the panels in accordance with the adopted principles of automation, process monitoring and control;

The specialists in heating and ventilation determine the overall dimensions of the facilities and their location for ventilation equipment and air conditioners;

The specialists in physical calculations plan the wall thickness between the radioactive circuit facilities which will provide shielding for the power plant personnel from radioactive radiation;

The specialists in construction determine the design layouts of the structures and the dimensions of the structural components and the "inside dimensions" of the facilities respectively;

The architects trace the ratio of the spaces of individual elements of the buildings and the building complex on the site, they determine the volumetric solution for the nuclear power plant structure; they define the people flows in plan and with respect to height in accordance with the division into zones and safety engineering rules.

The space planning and structural design of the building are determined first of all by the industrial process for which it is designed.

The form of the building depends on the form of the equipment and also the engineering requirements connected with the necessity or the possibility of access of people to the individual units of equipment. The united modular system (YeMS), standardization and unitization adopted in construction must be observed here.

The dimensions of the building depend on the space occupied by the equipment, the space required for the service personnel and the space taken up by the biological shielding; the weight of the shielding will have a significant influence on the structural solution of the building as a whole.

Building Layout Principle. The buildings or blocks of buildings for a given purpose are formed in accordance with the basic functional purpose of the main part of the facilities. For example, the set of facilities that service the reactor of a nuclear power plant is joined to the reactor section, the set of facilities that service the turbines are joined to the machine room.

The main building of modern nuclear power plant is the main facility in which the services that provide for generation of the electric power are concentrated. Usually the main facility consists of the reactor room and machine room, a specialized facility and electrical gear high-rise annex.

The equipment directly connected with the operation of the reactor, creating the necessary conditions for normal operation of it, and providing for safety in emergency situations is installed in the reactor room. All of the equipment of the primary circuit which operates with radioactive coolant and high pressure is placed in the reactor room of the power engineering units with the water-cooled, water-moderated power reactors having a two-circuit system.

The turbogenerator consisting of the turbines, the generator, condensers with condensate pumps, high and low pressure recovered heat heaters, the steam heater-separators and the high-speed regulators (BIU) for discharge of steam to the condensers and to the atmosphere, is placed in the machine room. If provision is not made for a complete deaeration of the condensate in the turbine condenser, deaerators are used in the secondary circuit which are installed either in the machine room or in the electrical equipment annex. The electrotechnical devices, the areas for the block panel, the safety and specialized water purification (SUZ and SVO) control system panels, the intake ventilation center, cable hookup and other services are placed in the same annex.

The machine room and the reactor room are connected by the main steam lines and feed water lines (for the two-circuit systems). Cables to the equipment in the reactor room and the machine room are laid from the instruments on the control panels in the control panel areas. Cables and pulse tubing from the equipment and the facilities of the radioactive circuit of the reactor room are laid to the dosimetry panel instruments [45, 53].

The Spetskorpus [special facility] can be designed either in the form of a separate building or as an annex to the machine room and the reactor room. The primary circuit services which can be taken outside the sealed space are located in the spetskorpus building. These include the units for purifying the coolant of the primary circuit, the workshops for repairing radioactive equipment, the storage areas for storing the fresh and spent fuel, the radioactive waste storage and other services connected with cleaning the radioactive circuit and storage of radioactive waste.

When laying out the structures of a nuclear power plant it is necessary to insure optimal conditions for installation, operation, maintenance and repair of the equipment in accordance with the requirements of the norms and rules and also to arrange this equipment and the communications among it in the minimum possible spaces.

One of the most important technical-economic indices of the space designs of electric power plants is the specific bulk of the main facility determined by the volume of the main facility ($m^3$) per kilowatt of installed power of the nuclear power plant. The smaller the volume of the structures, the greater the efficiency of the layout, the lower the capital expenditures when building the nuclear power plants, the cheaper each kilowatt of installed power and the smaller the proportion of the capital component in the cost of one kilowatt-hour of electric power generated by the electric power plant.

Decreasing the volume of the facilities implies a reduction in the following:

The consumption of materials and means for structural components, especially in the reactor room where the volume of the massive reinforced concrete shielding walls, floors and ceilings is measured in tens of thousands of cubic meters of reinforced concrete;

The consumption of lining and finishing materials, including expensive coatings in the radioactive circuit areas;

The expenditures on ventilation of the facilities which is especially important for the radioactive circuit areas where expensive filters are required to clean the air and its cooling system;

The length of the communications between individual groups of equipment at the nuclear power plants: the high and low pressure lines made of carbon and stainless steel, the acutely short monitoring-measuring and power cables, the pulse tubes made of stainless steel for the monitoring and measuring equipment.

The effort to reduce the volumes of the nuclear power plant facilities and increase the efficiency of the layout has led to maximum blocking of the structures.

Whereas the first nuclear power plants were laid out by the principle of each circuit in its own building, on the modern level a trend is clearly expressed toward maximum closeness of all systems to each other and maximum blocking of the main body of basic electric power plant services in one building. At the same time, when laying out the main facilities an effort is made to create a modular unit which can be repeated without alterations for nuclear power plants of different power. For this purpose, the systems and services required for the operation of one power unit are placed in one building, and the general plant systems which depend on the number of power units serviced by them are put in independent buildings. This layout principle makes it possible to create a standard power unit in which all equipment and communication systems between equipment are repeated without alterations.

The possibility of using the general plant systems not for one, but for two or several power units, naturally lowers the capital expenditures per kilowatt of installed power and the operating and maintenance expenditures on generating the electric power. Therefore the version is optimal where the final power of the nuclear power plant, the type and number of power units are defined from the very beginning of construction of the plant. The layout solutions for the main facility in this case must provide for using general plant systems for the largest number of power units.

The "startup complex" for which the required set of structures and services are installed providing for the possibility of startup under normal operation of the given power units before completion of the building of the entire power plant, is determined for each power unit.

If further expansion of the nuclear power plant is planned, this must be taken into account when laying out the main facility, providing for the installation of temporary ends and the possibility of communications between the power units under construction and future ones.

The layout of the nuclear power plant structures must correspond to the creation of safe and convenient working conditions for the service personnel in accordance with the requirements of the construction norms and rules SNiP II-M.2-72, SNiP II-A.5-70, SNiP II-A.4-62, the process designed norms [60], sanitary norms and rules [76, 77], and rules for electrical installations [68].

Sanitary Requirements on the Layout of the Structures. The layout of nuclear power-plant structures connected with the operation of the radioactive circuit equipment must exclude the possibility of harmful effects of radioactivity on personnel that service the nuclear power plant, the environment and the population living in the vicinity of the electric power plant.

The nuclear power plant facilities must be laid out beginning with the differentiated approach to the irradiation level. The norms NRB-69 [59] established three categories of irradiated people: category A -- the personnel (professional workers), people who work directly with the radiation sources or can be subjected to irradiation by the nature of their work; category B -- individual people from the population, the contingent living near the nuclear power plant; category C -- the population as a whole.

Among the personnel (category A), two groups are isolated: category A (a) -- people whose working conditions are such that the irradiation doses can exceed 0.3 of the annual MPD [maximum permissible dosage]; category A (b) -- people whose working conditions are such that the irradiation doses cannot exceed 0.3 of the annual MPD.

In connection with what has been indicated, all of the nuclear power plant territory, facilities and spaces must be divided into three zones [59]: monitored, sanitary-protected and observed.

The monitored zone includes the volumes, facilities and buildings or territory of the enterprise, organizations, laboratories, storage where it is possible to obtain more than 0.3 of the annual dosage permissible for the personnel (category A). In the monitored zone there is mandatory individual dosimetric monitoring.

The sanitary-protected zone is the territory around the enterprise in which it is forbidden to locate housing, children's institutions and also industrial and auxiliary installations not belonging to the enterprise for which the sanitary-protected zone has been established. The radiation situation must be monitored in the sanitary-protection zone.

The observed zone is the territory where the irradiation doses of the population living there can exceed the established limits. The radiation situation is monitored in the observed zone. The use of the land in this zone for agricultural purposes is limited.

Beginning with the indicated requirements, all of the production facilities of the nuclear power plant must be divided into two zones:

The monitored strict conditions ("dirty") zone in which the personnel working with the equipment of the radioactive circuit can come under the influence of radiation-harmful factors such as external radioactive radiation, pollution of the air in the facilities with radioactive gases and aerosols, contamination of surfaces with radioactive materials;

The unlimited free conditions ("clean") zone in which the effect of any radiation factors on the personnel is completely excluded.

Direct access between these zones is not permitted and must be realized only through a decontamination station. Complete change of clothes by the personnel is required.

Inside the zones, the facilities are laid out beginning with the requirements of the production process.

The strict conditions zone, in turn, must be broken down into three groups:

Unmanned facilities which the presence of people is forbidden when the reactor is in operation;

Semimanned facilities in which the periodic presence of people during operation of the reactor is possible for a time in which the total irradiation dosage received by the personnel will not exceed the permissible level [59];

Manned facilities where provision is made for the presence of personnel during the entire shift.

The repair and rebuilding of equipment in the unmanned facilities are accomplished with the reactor shut down. Personnel are allowed to pass from the semimanned facilities to the unmanned facilities (with the reactor not operating) through decontamination locks. When periodic visits to the unmanned facilities are required, stationary decontamination locks are installed; for unplanned visits, portable decontamination locks can be used.

When laying out the main facility, the operator and panel facilities (the modular control panels, the dosimetric monitoring panels, and so on) where constant presence of personnel is required must be placed in the free conditions zone.

Requirements on the Siting of Production Equipment. All of the equipment and lines in the main facility must be laid out so that when the reactor is not operating it was possible to examine and test both welded joints and the basic material of the equipment and lines, quickly replace and repair their basic subassemblies.

For the possibility of dismantling and installing the largest repairable pieces of equipment or bringing in fuel containers, provision must be made in the reactor room for a hatch located above the transport routes (road or railroad).

For installing large equipment that cannot be dismantled, a temporary installation opening is provided in the structural components of the reactor room.

Requirements on the Systems for Localizing Reactor Room Equipment Emergencies. The concentration of the equipment of the primary circuit in one space permits efficient provision of a seal in the case of an emergency (even in the case of a large scale emergency -- rupture of a pipe of maximum diameter), and it prevents discharge of radioactive materials outside the reactor room into the environment.

Complete localization of radioactivity when there is a break in the seal of the radioactive circuit is achieved by closing the high-speed fittings on the service lines running through the walls of the sealed facilities. The high-speed fittings are installed inside the sealed facility and must be protected from damage in the case of a possible rupture of the primary circuit, for example, by a shielding wall.

In order to perform the materials handling operations during operation of the nuclear power plant the following are provided:

As a rule one bridge crane is installed in the reactor room, the capacity of which is determined by the conditions of installation and dismantling of the heaviest element (the reactor vessel or the separator housing, and so on). The crane is controlled and guided remotely from portable and permanent, enclosed panels;

The auxiliary equipment located in the reactor room is laid out considering the possibility of servicing it by the main reactor room crane (special installation and repair areas are not provided in the reactor room);

The reactor room is equipped with freight and passenger elevators;

Bridge electric cranes (usually two) are installed in the machine room, the capacity of which is determined, as a rule, from the condition of lifting the generator stator;

In the machine room provision is made for installation and repair areas, the equipment for which is brought in by rail or motor transportation. In the machine room it is necessary to have no less than two entrances which provide for transporting equipment to the operating and expanded parts of the nuclear power plant;

Auxiliary equipment located in the machine room is laid out beginning with the possibility of servicing it by the main cranes in this room. In the case of placement of the auxiliary equipment outside the range of the main cranes, the corresponding lifting devices are used to service and repair it: overhead-track hoists, hoists or winches.

Requirements on Structural Components. When laying out the structures of nuclear power plants it is necessary to observe unitization and standardization of the buildings and structures adopted in the SNiP II-M.2-72 for production enterprises.

For the possibility of using standardized elements of the coverings, floors and ceilings, the dimensions of the bays of the nuclear power plant buildings must be taken as multiples of three meters; the column spacing of the frames of the buildings must be 6 or 12 meters.

The height of single-story buildings to the bottom of the supporting structures of the roofs and the heights of the floors of multistory production buildings at nuclear power plants determined by the process requirements must be taken as multiples of 0.6 meters. Deviation from this rule is permitted when laying out the facilities and the structural elements of the underground part of the buildings and structures.

The inside dimensions of the facilities of the radioactive circuit must be multiples of 100 mm.

The layout axes of the buildings and structures (tying of the walls to the layout axes and also the height of individual parts of the buildings and structures) must be designated in accordance with the SNiP II-A.4-62.

Requirements on the Layout of the Facilities in the Electrical Section. When laying out the main facility, the electrical section of the nuclear power plant (the distribution circuits, control panels, storage batteries, cable halfstories, and so on) must be designed considering the requirements of the Rules for Designing Electrical Installations [68].

The facilities for the distribution stations located within the main building are made without windows, with artificial lighting, and they must be reliably protected from moisture and dust.

When laying out the machine room it is necessary to provide for the possibility of assembly and repair of transformers in it using bridge cranes. For this purpose, an installation area must be provided in the machine room on which it is possible to roll the transformers from the transformer area beyond row A during repairs.

The dimensions of the area assigned for the central control panel of the nuclear power plant are taken beginning with the total power of the electric power plant. This facility must have no less than two exits (with a floor space of more than 200 $m^2$). The construction of one of the exits on the fire ladder landing is permitted.

The release of hydrogen and formation of explosive mixtures are possible in the storage battery facilities; therefore it is necesary to provide for entry in these facilities through a vestibule with two doors. The floors and ceilings of the battery room must be strictly horizontal and smooth. When using large-panel decking, holes are made in its ribs for free passage of air to the exhaust units in order to avoid accumulation of the explosive battery mixture in the facility.

Fire Safety Requirements. The layout of the nuclear power plant structures must be designed considering the possibility of safe evacuation of personnel through the evacuation exits in case of fire. In accordance with SNiP II-A.5-70 the exits are considered to be evacuation exits if they lead from the first floor areas directly outside or through a corridor, vestibule or stairwell; from the areas on any floor except the first, to a corridor or passage leading to a stairwell or directly to a stairwell having independent exit outside or through a vestibule; from one facility to adjacent ones on the same floor are provided with exits indicated in the preceding items.

The width of the evacuation doors must be no less than 800 mm, the height of the doors and passageways to the evacuation routes, no less than 2 meters. For the evacuation corridors from basement floors this height can be decreased to 1.9 meters, and for entrances to attics, to 1.5 meters. There must be no less than two evacuation exits from buildings. The evacuation exits must be located separately.

For facilities which are inside the building on any floor, it is permissible to design one door leading to the evacuation exits if the production is in category D and E[1] with respect to fire hazard, no more than 50 people work in the facility, and the area of the facility does not exceed 600 $m^2$.

From facilities with production in category E with a floor space of no more than 300 $m^2$ and no more than 5 people working per shift (on any floor except the first) one evacuation exit is permissible, which can be organized through the door to a steel stair with a slope of no more than 1:1 and width of no less than 700 mm. The enclosing structures of the stairs must be incombustible.

The fire safety measures must be taken into account when designing the cable layouts of nuclear power plants. The cable corridors and shafts are separated from other facilities by fire safety partitions. The tunnels and corridors are divided into compartments by partitions with self-closing fireproof doors. The passage of electric cables through the walls and the ceilings of cable half-stories, control panel facilities, cable tunnels, corridors, and so on is realized in metal tubes with reliable seal of the holes with easily packed incombustible material.

In the cable tunnels and halfstories provision is made for automatic firefighting equipment -- foam extinguishers.

## 3-2. Nuclear Power Plants with Vessel Type Reactors

The layout and the space planning designs of the principal structure of a nuclear power plant with vessel type water-cooled, water-moderated power reactors can be considered in the example of the Novovoronezh nuclear power plant. This electric power plant is the first high-power nuclear power plant in our country. It is being built in phases. Three phases have already been built, and the power of the four-power units has reached almost 1500 megawatts. The fifth power unit with a 1000 megawatt reactor is being built, and with its introduction the nuclear power plant will become one of the most powerful (2.5 million kilowatts) nuclear power plants in the world [84].

During the design and construction of the individual phases of the Novovoronezh nuclear power plant, the layouts of the principal structure have changed. In the example of the design and construction of the phases of the Novovoronezh nuclear power plant it is possible to trace the trends and the development of the nuclear power plants with water-cooled, water-moderated power reactors in our country and the variation of their layouts, respectively.

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[1] All production facilities are divided into five categories with respect to fire hazard: A, B, C, D and E. In categories A, B and C are production facilities connected with handling combustible substances and materials, and categories D and E are incombustibles.

First and Second Phases of the Novovoronezh Nuclear Power Plant

In the building of the principal structure of the nuclear power plant, the machine room, the deaerator stock, the reactor room with exhaust ventilation center and the spetskorpus [specialized facility] has been modularized. The layout of the principal structure is analogous to the layout of the principal structures of thermal electric power plants (Figures 3-1 and 3-2).

The flow chart of the first phase of the Novovoronezh nuclear power plant includes the VVER-210 reactor, six circulating loops consisting of the steam generator, the main circulating pump, the main circulating lines on which two main slide valves are installed to disconnect any loop from the reactor in case of emergency. Six steam generators produce dry saturated steam with a pressure of 33 MPa and moisture to 0.5%, which goes through the main steam lines and three AK-70 turbo-units with a unit power of 70 megawatts.

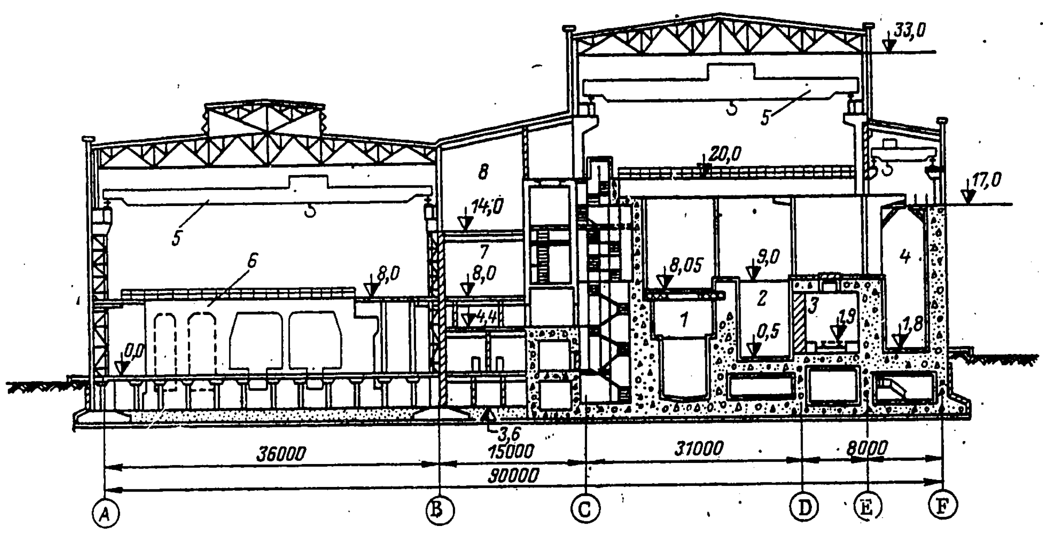


Figure 3-1. Transverse section of the principal structure of the first phase of the Novovoronezh nuclear power plant. 1 -- reactor pit; 2 -- fuel recharging basin; 3 -- transport corridor; 4 -- spent fuel holding basin; 5 -- bridge crane; 6 -- foundation under the turbo-unit; 7 -- electrical equipment facilities; 8 -- deaerator installation facilities.

Each loop of the primary circuit is placed in a separate rectangular box made of reinforced concerete providing biological shielding and taking an emergency pressure of 0.3 MPa. There are six such boxes -- with respect to the number of main circulating loops. This layout was adopted from the condition of repairing each loop without shutting down the reactor.

The second phase of the nuclear power plant with a reactor of 365 megawatts and five turbounits of 75 megawatts each has a more powerful reactor by comparison with the first phase; the modular consolidation of the first module is represented by the remaining parameters.

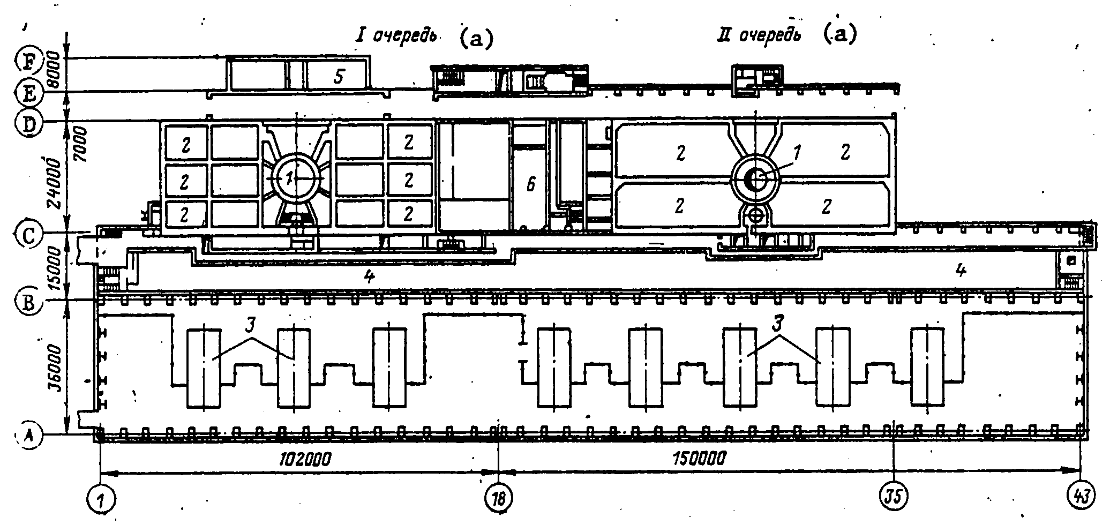


Figure 3-2. Plan view of the principal structure of the first and second phases of the Novovoronezh nuclear power plant. 1 -- reactor; 2 — steam generator; 3 -- turbo-units; 4 -- electrical equipment stack; 5 -- spent fuel holding basin; 6 -- special water purification.

Key: a. phase ...

Third Phase of the Novovoronezh Nuclear Power Plant

Two identical power units with VVER-440 reactors are installed in the principal structure in the third phase of the Novovoronezh nuclear power plant (Figure 3-3). The equipment of the primary circuit of each power unit includes the VVER-440 reactor and six circulating loops, each of which includes a steam generator, a main circulating pump, circulating lines 550 mm in diameter and the main slide valves (one for the hot and cold lines of the loop). In the secondary circuit with one power unit two turbounits of 220 megawatts each are installed. The reactor room is equipped with a crane set up common to the two power units; many of the auxiliary systems and equipment are also designed for the two power units.

All six circulating loops are placed in one common box having a special facility, the so-called deck, from which during operation of the power unit it is possible to inspect and monitor the condition of the electric motors of the main circulating pumps, the main slide valves and their auxiliary equipment. The electric motors are placed on the deck and separated from the unmanned facility -- the steam generator box.

By comparison with the first two phases, the third phase of the nuclear power plant includes significant alterations.

The principal structure of the third phase combines the machine room and the reactor room, the electrical equipment stack and the exhaust ventilation center in one building. In plan view the principal structure is two rectangles joined by the long sides, symmetrically arranged with respect to the transverse axis (Figure 3-4).

When designing the layout of the main facility of the third phase (Figures 3-5, 3-6) an effort was made to do away with the traditional space design of the main facilities of the thermoelectric power plants. The electrical equipment annexes made in the form of glassed buildings are adjacent on one level with the exhaust ventilation center stack around the rectangular, dead space of the reactor room. The difference in height of these spaces emphasized by the vertical pull rods on outside faces of the reactor room walls, isolates its space as predominant, corresponding to its functioal significance. This relation of the spaces is intensified by the flat roofs of the stacks, the reactor room and the machine room.

The reactor room is made up of the following basic units. Around the reactor pit the facilities are located where the equipment belonging to each power unit is placed -- the recharging and spent fuel holding basins with cooling circuit, the steam generator and main circulating pump boxes, the systems for makeup of the primary circuit, compensation for blow down of the steam generators, the sensors of the monitoring and measuring instruments and the intermediate cooling system circuits. With respect to height, this equipment occupies the space from the floor-ceiling after the 10.5 meter level to the foundation plate. Between the two power units (in plan view) the general station equipment is located consisting of the units for purifying contaminated water, the local panel of the reactor room, the repair workshops of the primary circuit, the transport railroad corridor, the fresh fuel assembly, the column pipe service corridor, and the storage facilities for the activated equipment and washing the large equipment.

The reactor is installed in a reinforced concrete shielding pit, in the upper part of which annular cable service corridors have been provided. Around the reactor in a single box 42 × 39 meters in size are six circulating loops of the power unit. The electric motors, the auxiliary circuits of the pumps and their equipment are in a separate facility above the main circulating loops.

The level of installation of the steam generator was determined from the condition of creating natural circulation required to remove residual heat released during shutdown cooling of the reactor.

The entrances to the pump and steam generator boxes were provided from the exhaust ventilation center corridor, from the intermediate circuit facility of the main circulating pumps through the vestibule of the valve chamber of the expansion tanks.

The trestles between the main facility and the spetskorpus [specialized facility] is adjacent to the central part of the reactor room. The pipelines for hydraulic discharge of the ion-exchange filters are routed in the "dirty" pipe service corridor; the corridor is also used for transporting the dry waste raised from the spent filters of the special ventilation units to storage. In addition, the communications between the primary facility and spetskorpus are maintained through an underground through pipe tunnel. The facilities of the primary circuit where the equipment is placed are laid out in a single sealed space, and they communicate with each other through openings. These facilities are designed for emergency pressure of 0.2 MPa.

Two doors are installed at the entrance to the sealed facilities of the primary circuit: shielding, located on the sealed facility side and designed for a pressure of 0.2 MPa, and light sealed, designed for rarefaction to 5 Pa. The space between these doors is connected to the exhaust ventilation.

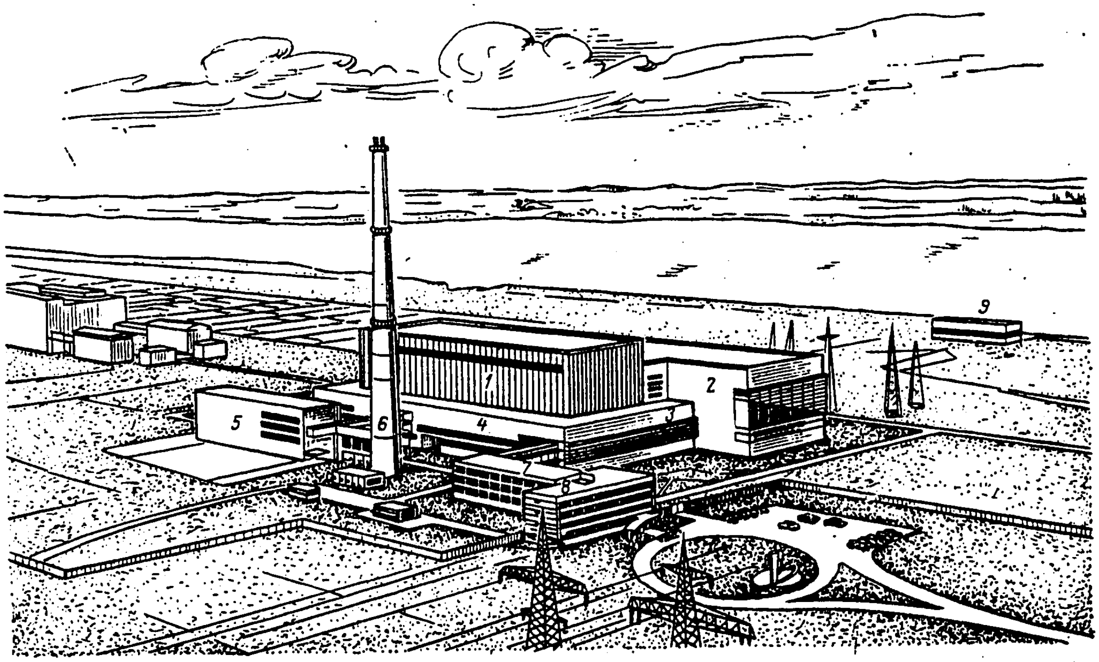


Figure 3-3. General view of the third phase of the Novovoronezh nuclear power plant. 1 -- reactor room; 2 -- machine room; 3 -- electrical equipment annex; 4 -- ventilation center; 5 -- auxiliary spetskorpus; 6 -- vent pipe; 7 -- sanitation and general services building; 8 -- administrative building; 9 -- service water supply pumping station.

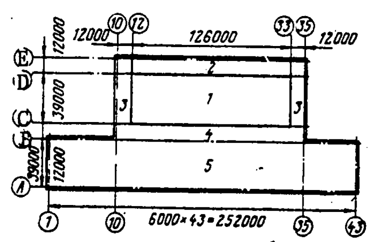


Figure 3-4. Layout of the areas of the main facility of the third stage of the Novovoronezh nuclear power plant. 1 -- reactor room; 2 -- ventilation center; 3 -- transverse electrical equipment stack; 4 -- longitudinal electrical equipment stack; 5 -- machine room.

The entrance to the facility for servicing the main circulating pumps and the emergency exit from it are realized through sealed locks which have two doors each designed for a pressure of 0.2 MPa each. The door openings are 900 mm and 600 mm wide for the possibility of transporting equipment and passage of personnel, respecively. The height of the doors, as a rule, is 1600 mm, and in individual cases where it is permissible by the operating conditions, 1200 mm. The sealed shielding

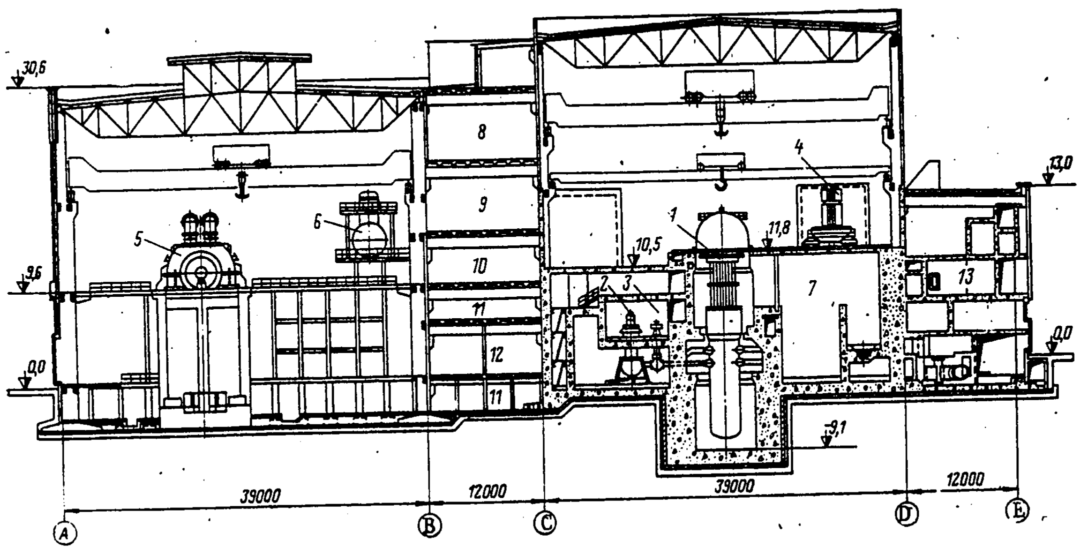


Figure 3-5. Transverse section of the main facility of the third phase of the Novovoronezh nuclear power plant. 1 -- reactor; 2 -- steam generator; 3 -- main circulating pump; 4 -- main circulating slide valve; 5 -- turbo-unit; 6 -- deaerator; 7 -- fuel recharging pool; 8 -- intake ventilation center; 9 -- pipe corridor; 10 -- panel facilities; 11 -- cable halfstory; 12 -- distribution station facility; 13 -- exhaust ventilation center.

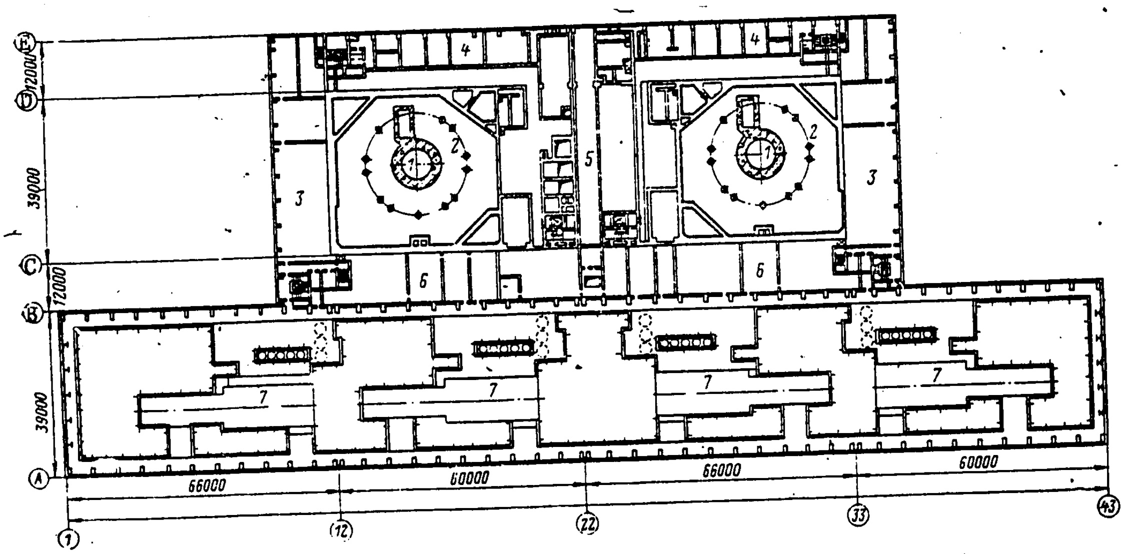


Figure 3-6. Plan view of the main facility of the third phase of the Novovoronezh nuclear power plant. 1 -- reactor; 2 -- steam generator box; 3 -- facility for the modular control panel; 4 -- exhaust ventilation center; 5 -- transport corridor; 6 -- distribution station facilities; 7 -- turbounit.

doors and also the factory-delivered hatches jointly with the fittings are subjected to hydraulic testing at the factory.

Four 220 megawatt turbounits are located in the machine room. The machine room is 252 meters long: 42 spans of 6 meters each. The turbounits are installed two for each power unit, one pair mirroring the other. This installation of the turbo-unit was selected to reduce and simplify the basic steam line routes.

The service level of the turbounits is 9.6 meters; the deaerator tanks are installed at the same level and in row B. The width and length of the machine room is determined by the dimensions of the turbounit cells and their orientation in the longitudinal or transverse direction.

The performed technical-economic comparison demonstrated that the versions of arrangement of the turbounits are in practice different. The version with longitudinal arrangement of the turbounits is insignificantly more economical as a result of decreasing the routes of the circulating waterlines and reducing the cost of the crane as a result of smaller dimensions of it. The practice of building electric power plants permits the conclusion to be drawn that with an increase in power of the turbounits, their transverse arrangement is more efficient.

In the machine room of the third phase of the Novovoronezh nuclear power plant the turbounits are installed in the longitudinal direction which naturally has led to a decrease in the span of the machine room from 51 meters (with transverse arrangement of the turbounits) to 39 meters with simultaneous increase in length.

The entrance to the machine room is realized through a transverse railroad track laid through the reactor room between axes 22-23. In addition, for repair of the transformers an entrance has been provided from the permanent end of the machine room with coordination of the axis of the railroad track at a distance of 12.8 meters to row A.

The erection sites in the machine room are located along the transverse railroad track between the power units and at the permanent end.

The electrical equipment stacks have a span of 12 meters and are arranged as follows: longitudinal on axes 10-35 between the machine room and the reactor room, and the transverse ones are adjacent to the ends of the reactor room.

The exhaust ventilation center with a span of 12 meters servicing the reactor room is located along it between rows D and E. The floors of the ventilation center have the following elevations: -1.8, ±0.0, +2.7, +6.3, and +10.5 meters.

The fans of the recirculation systems in the concrete shielding, air coolers and valves of the recirculation system installed in concrete niches covered by sealed hatch covers, aerosol and iodide filters, the intake plenums of the exhaust units, the valves and gates (for the aerosol filters concrete shielded cells are provided) and also the equipment and the collecting box for the removed air of the reactor room are located in the ventilation center. Levels -1.8 meters and ±0.0 are serviced by monorails.

The spent aerosol filters are transported in a shielded container which is moved to the dry waste storage located in the spetskorpus by a battery-operated truck.

The combined spetskorpus of the third phase of the Novovoronezh nuclear power plant is an independent building in which the special water purification systems and the liquid and dry waste storage are located.

The special water purification (SVO) building is multistory with a basement; it is 78 meters long (13 spans of 6 meters each) and 18 meters wide.

Stairwells are placed at the ends of the building. The entrances to all facilities are from corridors connecting the stairwells. Motor vehicle entrance is provided to the corridor located at the 0.0 level on the principal facility side. Part of this corridor is used to wash the motor vehicles to remove radio-active contamination. The assembly room serviced by a ten-ton bridge crane is located at the 7.2 meter level; the crane track is at the 18.0 meter level.

The service personnel get into the special water purification building from the sanitation and general services building, going through the corridor at the 6.3 meter level in the exhaust ventilation center of the reactor room and then over the trestle between the principal facility and the spetskorpus. Using the monorail with a 5 ton electric hoist, the containers with solid radio-active waste are transported on the same trestle from the primary facility to the dry waste storage.

Thus, the special water purification building is included in the "dirty" zone complex to which access is prohibited except through the decontamination station.

The liquid waste storage, which has dimensions of 33 × 44 meters in plan view and -3.6 and 0.0 meter levels, is adjacent to the special water purification building and is connected to it by a pipe corridor and service corridor at the 0.0 meter level.

Transport Communication and Evacuation Exits. The transverse railroad intersects the machine room and the reactor room, that is, it runs through the "dirty" and "clean" zones; therefore the gates at the exit from the reactor room are closed during normal operation of the nuclear power plant.

The reactor room which is common to the two power units is serviced by two electric bridge cranes of 250/30 and 30/5 ton capacity. The highest crane capacity is selected from the condition of lifting the reactor vessel during installation of it. The level of the track for this crane is 28.5 meters. It is designed to transport heavy equipment and subassemblies and also for equipment installation. The crane is remote controlled. For handling radioactive loads the crane is equipped with a remote guidance system by means of which, by assignment of the operator it can service points for which the coordinates have been selected in advance with an accuracy of ±10 mm.

In the automatic operating mode the crane is controlled from the central panel located at the 14.7 meter level of the reactor room through a special opening into the reactor room. The control of the crane during operations not connected with coordinate guidance is from two auxiliary panels located directly at each reactor at the 10.6 meter level.

The 30/5 ton crane of the reactor room is designed to transport loads weighing up to 30 tons. Its track is at the 22.5 meter level. The speed of transporting loads by this crane is higher than by the 250 ton crane. The operation of the two cranes provides all of the required load lifting and transporting operations in the reactor room.

The machine room is serviced by two electric bridge cranes of 125/20 tons each. The crane track is at the 17.5 meter level. The load lifting capacity of the crane is calculated from the condition of lifting the generator stator by the two cranes, using a crossarm.

The service personnel get into the strict conditions zone through a crosswalk from the sanitation and general services and the laboratory building located on the permanent end of the reactor room. The bridge is two-story, the lower story is designed for passage to the free-conditions zone, and the upper story, for passage to the strict conditions zone.

The entrance and exit from the strict conditions facilities are realized through the decontamination station located in the sanitation and general services building. The dosimetric monitoring of the personnel entering and leaving the area is realized from the work areas of the duty dosimetric specialist located at the entrance to the decontamination station.

If it is necessary to perform repair work in the facilities with increased radio activity, a portable decontamination lock is installed at the door of such a facility for washing the film clothing and overalls of the service personnel.

In the facilities in the strict conditions zone four stairways are provided: two basic three abreast with passenger elevators located in the exhaust ventilation center with emergency exits to the street at the 0.0 meter level and two emergency two abreast located in the reactor room and row C on both sides of the railroad track with exit to the railroad corridor. The necessity for locating the stairs on two sides arises from the fact that the transverse railroad entrance to the reactor room breaks the service lines. The emergency exits from the stairs to the street and to the railroad corridor from the strict conditions zone during normal operation of the electric power plant are closed and sealed.

Two three-ton freight elevators and two 100 kg freight elevators are provided for bringing equipment up in the reactor room.

The floors of the machine room and the longitudinal electrical equipment stacks at levels -3.6 to +9.6 meters are joined by two stairways with 350-kg passenger elevators. The exit to the street from these stairways is provided at level 0.0 meters. The stairway located on the permanent end of the principal facility communicates through a corridor with the "clean" level of the crosswalk to the sanitation and domestic services building. The levels of the longitudinal electrical equipment annex at heights from 14.7 to 21.9 meters are serviced by their own two abreast stairways with 350 kv passenger elevators.

Localization of Emergencies. For localization of an emergency with equipment in the primary circuit a sealed space has been created in which a rise in pressure during the emergency is possible. The basic sealed space is the main circulating pump and steam generator box joined to the expansion tank facilities, the valve chambers, the reactor pit, and so on.

The discharge of the steam-air mix during emergencies in the individual circuits takes place to the pump and steam generator box. In case of an emergency in the boxes, sprinklers begin to operate which condense the emergency steam and thus lower the emergency pressure in the boxes.

Fourth Phase (or Fifth Power Unit) of the Novovoronezh nuclear power plant (Figure 3-7)

The fifth power unit is a new phase in the development of nuclear power plants with water-cooled, water-moderated power reactors in connection with a sharp increase in the unit power of the basic equipment and with respect to the adopted design solutions.

The primary circuit of the power unit includes a VVER-1000 reactor with a unit thermal power of 3000 megawatts or 1000 megawatts electric power, respectively; four main circulating loops, each of which consists of a steam generator with a capacity of 1500 tons/hour of dry saturated steam at a pressure of 6.4 MPa, the main circulating pump of the packing gland type with 19,000 $m^3$/hr output, the main circulating lines 850 mm in diameter with the main shutoff valves installed on them (one on the cold and one on the hot lines). The steam-water type expansion tank with electric heaters is included in the part of the loop that cannot be cut off.

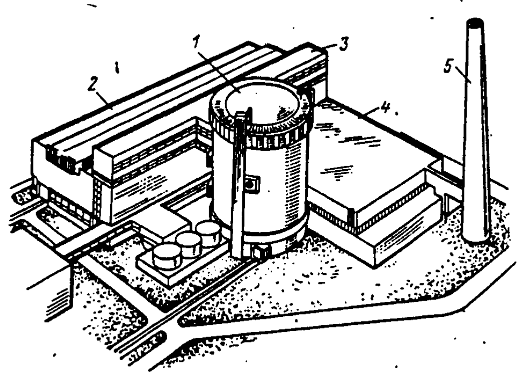


Figure 3-7. General view of the fifth power unit of the Novovoronezh nuclear power plant. 1 -- reactor room; 2 -- machine room; 3 -- electrical equipment stack, 4 -- spetskorpus; 5 -- vent pipe.

The secondary circuit consists of a number of systems, the basic ones of which are the following: two K-500-60/1500 turbounits, the system of steam lines and high-pressure feed lines, the steam generator blowdown system, the drainage tanks of the machine room and the desalinated water tank, the boiler unit, the low-pressure steam lines and auxiliary secondary circuit systems.

The main facility of the fifth power unit (Figure 3-7) consists of three spaces connected to each other: the reactor building, the special services building (spetskorpus) and the machine room building (Figures 3-8, 3-9).

The reactor building is in the form of a protective envelope (Figure 3-10) of prestressed reinforced concrete with inside metal lining. The envelope is in the form of a vertical cylinder with an outside diameter of 48 meters and 76.4 meters high with elliptic dome.

The envelope is designed to localize an emergency in case any of the lines break, including instantaneous transverse rupture of the main circulating line. In the case of a maximum emergency, flying objects can occur — metal fragments from the equipment or the structural components which can destroy the lining and unseal the envelope. In order to exclude this possibility, the part of the circuit where flying objects can occur is shielded by reinforced concrete shields which usually are used simultaneously as the inside walls.

In case of a maximum emergency the steam formed in the boxes can be released to the upper part of the envelope and uniformly distributed throughout its entire volume, which is achieved by organizing openings between the envelope facilities [17]. The development of a maximum emergency takes place so quickly that the crossectional area of the connecting openings is quite large (120-150 $m^2$). The necessity for communication of the reactor section facilities predetermined the layout of the envelope in the form of a common space not having air tight partitions. This solution offers the possibility of organizing the removal of excess heat, ventilation of the envelope and purification of the air by a single recirculating ventilation system. By radiation safety conditions all of the facilities included in the sealed part of the envelope are converted to unmanned facilities, and access to the envelope when the reactors operate is forbidden.

The sealed part of the reactor section begins above the floor at 12.3 meter level. The unsealed part is located below the 0.0 level.

The sealed part of the envelope is designed for a pressure of the radio-active steam-air medium to 0.5 MPa.

All of the basic equipment of the primary circuit of the reactor is placed within the limits of the sealed areas of the shell. The steam generator and main circulating pump box are located in the central part (from the 22.8 meter level to the ceiling at the 38.1 level); here, in addition to the equipment of the main circulating loops there are also the recovery heat heat-exchangers and aftercoolers for the blowdown water of the primary circuit and the organized leak cooler. Around the box are two tanks of the system for emergency cooling of the reactor zone (SAOZ). Two more SAOZ tanks are located in the expansion tank area. The communications with the railroad are through a special sealed hatch at the 0.0 level which for normal operation of the power unit is closed by a removable sealed cover. The hatch opens if the reactor is shut down for recharging with fuel, when it is necessary to remove the spent fuel held in the pool from the envelope or to deliver or remove equipment, materials and radio-active waste from the envelope.

From the railroad corridor side the fuel holding pool is adjacent to the reactor pit; on the diametrically opposite side is the expansion tank and bubbler area.

Around the steam generator and the main circulating pump box and the expansion tank area at the 20.3 meter level is the pipe service corridor.

The ceiling over the steam generator box and the expansion tank area is the floor of the central room of the reactor section. The central room is serviced by a 400/80 ton circular bridge crane. The crane tracks are at the 54.95 meter level. Under the steam generator and main circulating pump box at the 12.3 meter level are the ventilation systems of the envelope. The transport corridor is located there above the railroad corridor.

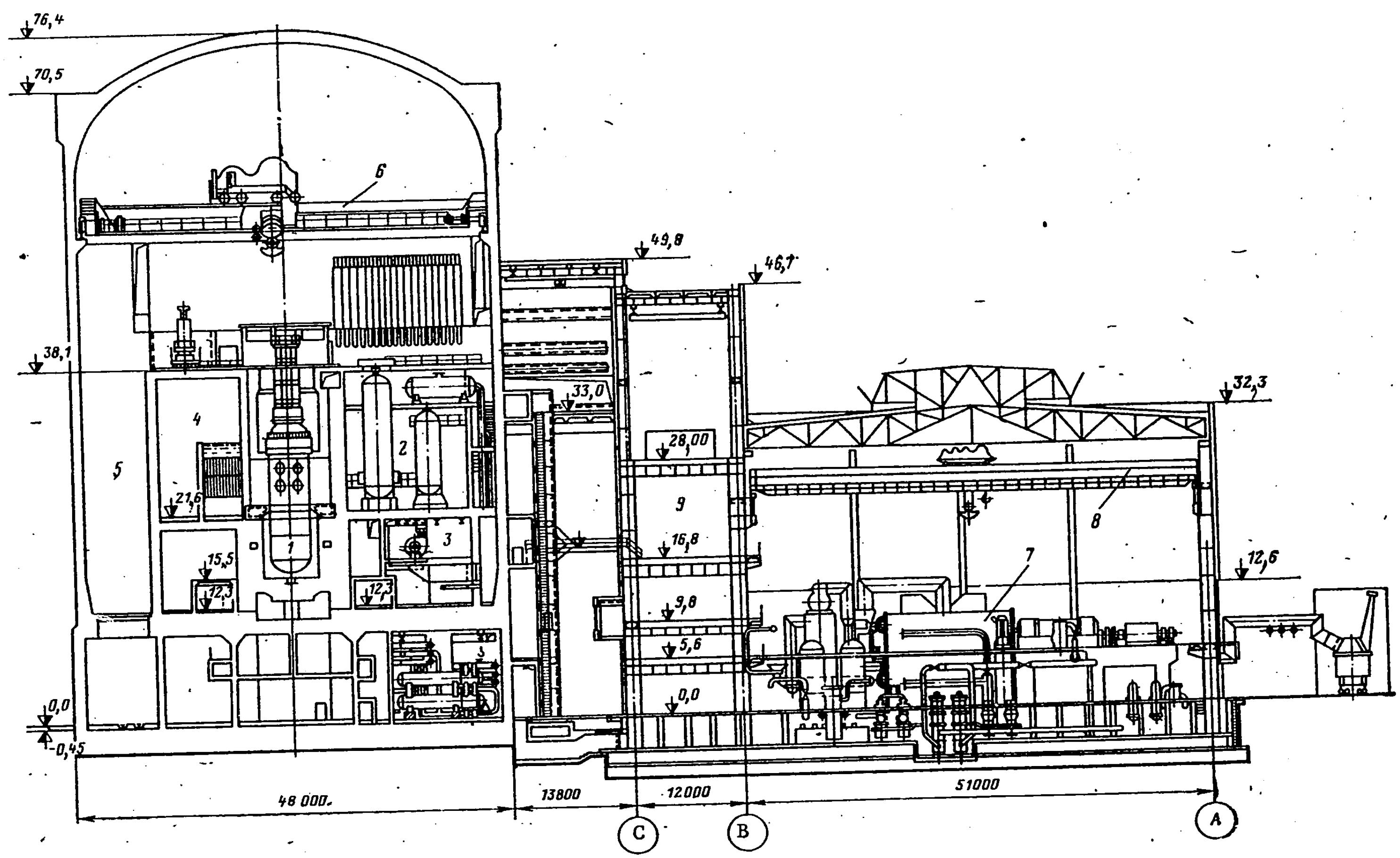


Figure 3-8. Transverse section of the main facility of the fifth power unit of the Novovoronezh nuclear power plant. 1 -- reactor; 2 -- expansion tank area; 3 -- ventilation unit; 4 -- fuel recharging pool; 5 -- transport shaft; 6 -- circular crane of the reactor section; 7 -- turbounit; 8 -- machine room bridge crane; 9 -- electrical equipment annex.

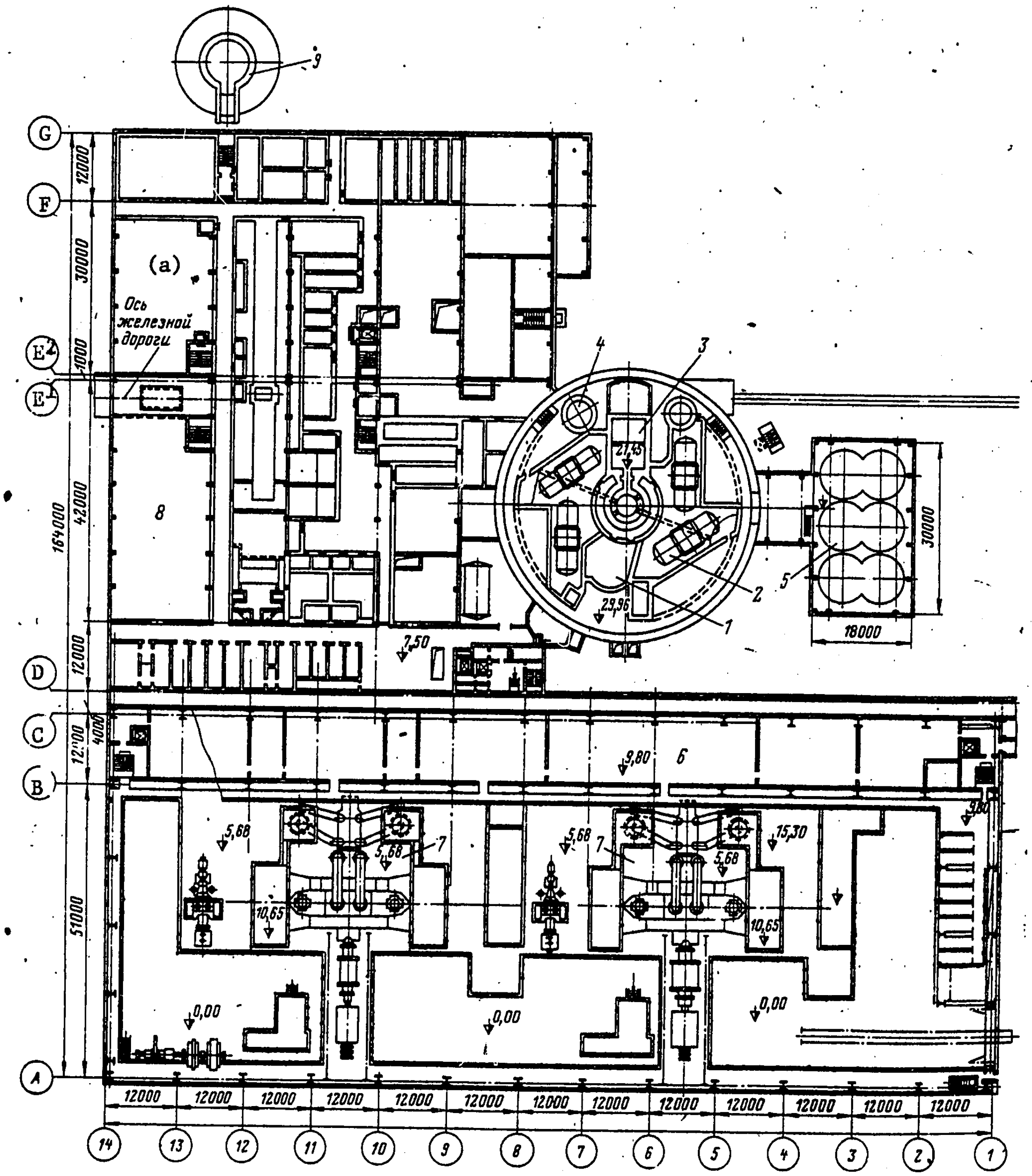


Figure 3-9. Plan view of the main facility of the fifth power unit of the Novovoronezh nuclear power plant. 1--reactor; 2--steam generator; 3 -- fuel recharging pool; 4 -- shaft for inspecting the top block of the reactor; 5 -- boric acid tank; 6 -- electrical equipment annex, 7 -- turbounit; 8 -- special water purification facility; 9 -- vent pipe.

Key: a.





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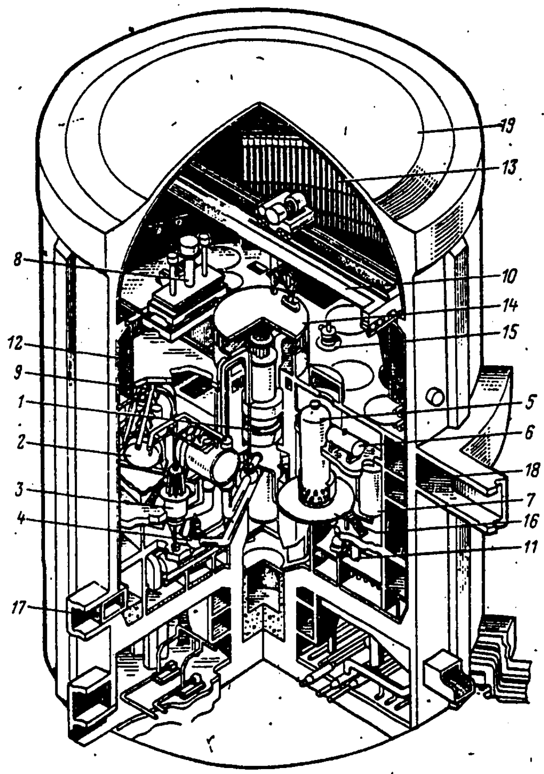


Figure 3-10. Reactor section of the fifth power unit of the Novovoronezh nuclear power plant. 1 -- VVER-1000 reactor; 2 -- PGV-1000 steam generator; 3 -- main circulating pump; 4 -- main shutoff valve; 5 -- expansion tank area; 6 -- bubble tank; 7 -- tank for emergency reserve of boron solution; 8 -- recharging machine; 9 -- main steamlines; 10 -- circular electric bridge crane; 11 -- centrifugal fan; 12 -- ventilation box; 13 -- spare SUZ rod; 14 -- cover over the concrete reactor pit; 15 -- hatch over the main shutoff valve; 16 -- service area; 17 -- main lock; 18 -- electrician's area; 19 -- reinforced concrete protective envelope.

Under the concrete reactor pit are the ionization chamber drives.

The air from the facilities included in the reactor envelope is purified of iodine and aerosols by special filters installed in the closed recirculating ventilation systems in the facility at the 12.3 meter level.

All of the operations with respect to transporting large loads inside the reactor section envelope are performed using the circular electric bridge crane.

In the machine room with a 51 meter span are two turbounits (Figure 3-9). By comparison with the longitudinal layout, transverse arrangement of them made it possible to decrease the length of the machine room, reduce the length of the basic steamlines and also the circulating lines. The length of the machine room which is equal to 156 meters (13 spans of 12 meters each) was determined by the dimensions of the turbounit cells of 60 meters each and also three additional bays for location of auxiliary general-module equipment and the assembly areas. The turbounit service level (5.6 meters) was determined by the location of the condensers: for the K-500-60/1500 turbounits, in contrast to the traditional basement location, lateral location of the condensers is used. On the permanent end of the machine room provision is made for a railroad entrance which is tied to row A at a distance of 8 meters to provide for the railroad clearance.

Two bridge cranes are installed in the machine room. The crane capacity of 120/20 tons was selected from the condition of transportation of the generator stator weigh- 230 tons and the low-pressure cylinder rotor of the turbine weighing 156 tons during installation and repair.

The layout of the machine room was developed beginning with the condition of placement of the heavy equipment in the service zone by the bridge cranes and also the possibility of getting around each turbine and along the entire row A.

There are three assembly areas provided for dismantling the equipment during installation and repair -- two at the end of the machine room and one in the middle between the turbines. The common area of the assembly sites is 1300 $m^2$. It is determined by the conditions of the necessity for repairing one turbine, simultaneous preventive inspection of another and inspection of one transformer.

The materials handling operations in the pipe corridor are realized using a five-ton overhead single-track electric crane. In addition, on the permanent end there is a one-ton freight-passenger elevator.

Along the length of row B is the electrical equipment stack with a 12 meter span adjacent to the machine room. The electrotechnical devices (distribution of stations, inhouse transformers, and so on) are located in the spaces from the -4.1 meter level to the +9.8 meter level. The modular control panel is located at the 9.8 meter level, from which all of the basic and auxiliary systems of the power unit are controlled (the reactor, the turbounit, diesel generators, operating and spare transformers, pumps, and so on), and the panel for the safety and control rod system (SUZ) is also located at this level.

The intake ventilation center is located at the 16.8 meter level. It provides for ventilation of the electrical equipment stack. Basic steam lines from the steam generators to the turbine and the feed water lines which enter the stack from the sealed envelope of the reactor section at the 17.6 and 18.6 meter levels are run at the 16.8 meter level.

The special service building is located on the temporary end of the machine room and is directly adjacent to the electrical equipment stack. The special service building is 60 meters wide and 84 meters long. With respect to width it is divided into four spans of 15 meters each. The equipment of the special service building is located at the -1.2, +7.5 and +12.5 meter levels.

The systems servicing the sealed envelope (makeup pumps, intermediate circuit, the circuit for shutdown cooling of the pool, the installation for purifying the coolant of the primary circuit and the pool) and the workshops for repairing radioactive equipment are concentrated in the special service building.

The storage area for fresh and spent fuel and the equipment for purifying the trap water, purification of the process blowers, bituminization of liquid waste and briquetting of soft waste are located in this building. The "dirty" tank setup for the electric power plant is located at the -1.2 meter level. The exhaust ventilation center is at the top levels.

The storage for solid and liquid waste which is also part of the specialized service building is serviced by a five-ton traveling crane.

Evacuation System of the Main Facility. The main entrance to the main facility is from the sanitation and general services building over a crosswalk. The reactor section has two exits through sealed locks: one at the 16.4 meter level to a covered passage leading to the specialized service building, and the other at the 35.0 meter level to an open stairway located on the outside of the reactor section. The areas for operative servicing of the reactor section are connected to each other by metal stairs.

Two stairways are provided on the two ends of the electrical equipment stack. The stairway on the permanent end is equipped with a 1000 kg freight-passenger elevator. The same stairways are used for access to the machine room.

Table 3-1. Indices of the construction phases of the Novovoronezh nuclear power plant

| Indices | VVER-210 | VVER-365 | VVER-440 | VVER-1000 |
|---|---|---|---|---|
| Year of beginning construction | 1957 | 1963 | 1967 | 1972 |
| Electric power of the reactor, megawatts | 210 | 365 | 440 | 1000 |
| Unit power of the turbounit, megawatts | 70 | 73 | 220 | 500 |
| Number of turbounits in the power unit, pieces | 3 | 5 | 2 | 2 |
| Number of loops in the primary circuit, pieces | 6 | 8 | 6 | 4 |
| Specific indices of the main facility: | | | | |
| cubic space, $m^3$/kilowatt | 1.43 | 1.10 | 0.83 | 0.56 |
| volume of concrete, $m^3$/kilowatt | 0.29 | 0.17 | 0.10 | 0.09 |
| construction metal consumption, kg/kilowatt | 11.0 | 9.0 | 6.0 | 6.0 |
| weight of equipment, kg/kilowatt | 74.0 | 50.0 | 40.0 | 20.5 |

An analysis of the specific indices characterizing the floor space solutions with respect to individual phases of the Novovoronezh nuclear power plant (Table 3-1) indicates significant improvement of them. Thus, the specific space of the basic buildings of the third power unit of the Novovoronezh nuclear power plant by comparison with the same index of the first power unit decreased by 1.7 times, the specific concrete consumption was cut by 2.9 times, and the consumption of construction metal, by 1.8 times.

Further improvement of the nuclear power plants with water-cooled, water-moderated power reactors will proceed along the path of increasing the unit powers of the basic equipment, improvement of the efficiency of the layouts as a result of decreasing the overall dimensions of the equipment and more efficient form of it.

Layout of the Main Facility by the Modular Principle

When laying out the main facility by the modular principle, all of the systems providing for radiation and nuclear safety, emergency shutdown, shutdown cooling, the removal of residual heat releases and the required post emergency measures are provided for each power unit.

The general plant systems required to provide for operation of the power units under normal operating conditions are isolated in individual structures of the nuclear power plant laid out in accordance with their functional attributes. Thus, the general plant special water purification units are placed in a separately standing specialized service building.

With this layout all of the equipment and systems of each power unit are placed in an independent building of the main facility 240 meters long with an overall width of 66 meters, including the following:

A machine room with electrical equipment stack annexed to row B, a deaerator stack in which the modular panel with IVM and ventilation system are also located; the reaactor section consisting of a sealed envelope 45 meters in diameter and 54 meters high and the enclosing structure 66 × 66 meters in plan (Figure 3-11).

The reactor section of the VVER-1000 power unit consists of a sealed section -- the envelope -- and an unsealed section -- the enclosing structure. The basic equipment of the power unit with high-potential radioactive coolant (the reactor, steam generators, main circulating pumps, expansion tanks, main circulating lines, SAOZ tanks, and so on) are located in the sealed part of the reactor section. The sealed part consists of two spaces -- top and bottom with air communications. The top space is a cylinder with inside diameter of 45 meters with a dome-shaped top. The bottom space of the sealed section is a cylinder with inside diameter of 26 meters coaxial with the top cylinder and supported on the foundation plate of the reactor section.

The unsealed part of the reactor section is square in plan view, 66 meters on a side, encompassing the perimeter of the envelope. The modular process systems which by nature of the production processes and degree of pollution with radioactive materials must be in the strict conditions zone placed in the unsealed part of the reactor section. In order to improve the reliability of the communications of the indicated process systems with the systems under the envelope, under conditions of seismic effects the surrounding structure and envelope of the reactor section are supported on a single foundation plate. The location of the modular systems in the enclosing structure of the reactor section also permits maximum reduction of service lines and pipelines.

The delivery of materials to the surrounding structure and the envelope of the reactor section is by the railroad access to the reactor section under the envelope or structure cranes.

One 1000 kilowatt turbounit is installed in the machine room. The machine room stand is taken as 51 meters. The operative service level of the turbine is +15.0

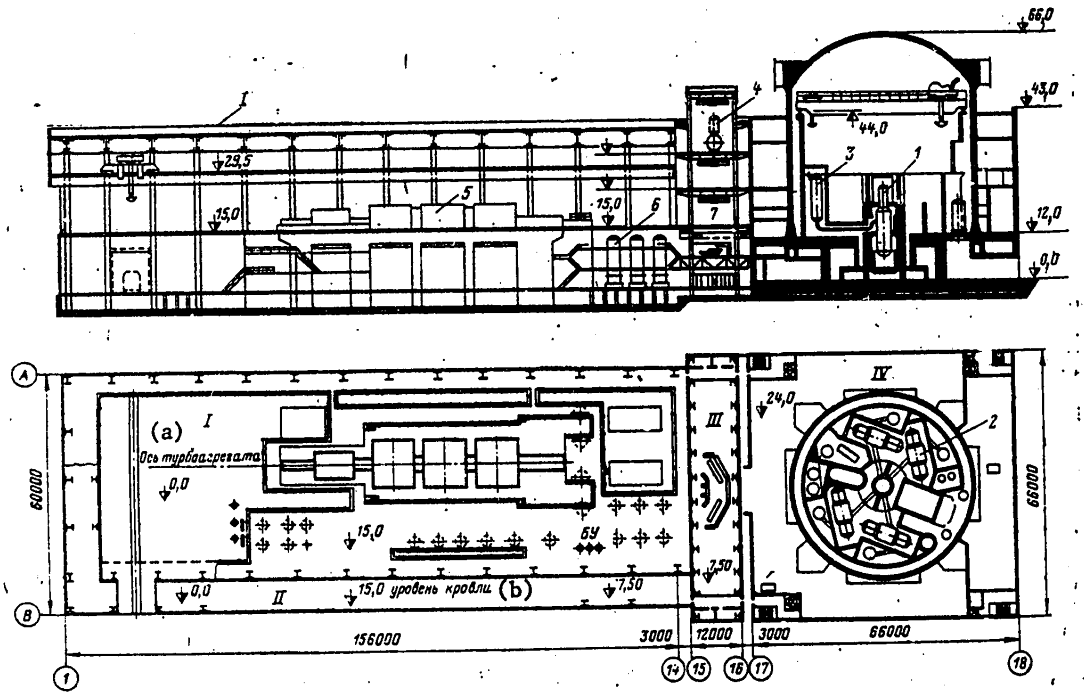


Figure 3-11. Modular layout of a power unit with VVER-1000 reactor. I -- machine room; II -- electrical equipment stack; III -- deaerator stack; IV -- reactor section; 1 -- reactor; 2 -- steam generators; 3 -- tank for the emergency zone cooling system (SAOZ); 4 -- deaerator; 5 -- turbounit; 6 -- high pressure heater; 7 -- module control panel.

Key: a. axis of the turbounit
b. roof level

meters, the turbine cell is 108 meters. A motor vehicle access is provided in the machine room along row A.

The railroad access (cross) is provided with clearance of 18,000 mm to axis 1, which was determined beginning with the condition of installing the generator stator.

Considering the layout of the turbounit and the dismantling of the equipment for repair, the length of the machine room is 156 meters.

The deaerator stack with a 12 meter span is adjacent to the machine room on the end facing the reactor section. The ceiling level of the deaerator unit is 34.2 meters.

# CHAPTER 4. CONSTRUCTION DESIGNS OF NUCLEAR POWER PLANT BUILDINGS AND STRUCTURES

## 4-1. Structural Design of Nuclear Power Plant Buildings

A nuclear power plant has buildings and structures for different purposes and, correspondingly, of different structural execution. These include the multistory and multibay building of the main facility with massive reinforced concrete structural elements which enclose the radioactive circuit; the separately standing buildings of the auxiliary systems, for example, the chemical purification, diesel generator, nitrogen plant, usually executed as prefabricated reinforced concrete standard structures; underground channels and tunnels, both passable and impassable for the cables and communications lines between systems; above-ground trestles which join the main building and auxiliary buildings and structures and also the buildings of the administrative sanitation and general services building (see Chapter 3).

The most complicated and responsible building of a nuclear power plant is the main building, which is a system of structures formed in the general case from frame structural components (the machine room, the electrical equipment annex, the spetskorpus [specialized facility]) and the massive reactor section structures.

The structural designs of the main buildings of nuclear power plants can be considered in the example of the Novovoronezh Nuclear Power Plant (see Figures 3-1 to 3-10).

### Main Building of a Nuclear Power Plant with VVER-440 Reactor

The structural designs of the frame of the main building of a nuclear power plant with VVER-440 reactor (see Figures 3-4 to 3-6) consist of columns which are 1500×600 mm in cross section in the machine room, 1200×600 mm in the reactor room, 800×600 mm in the exhaust ventilation center and girders 1400×600 and 1000×600 mm in cross section. The column joints to the foundations are "wet." The installation joints of the column elements are "dry," finished off at the plant.

The stability of the building in the transverse direction is insured by the monolithic mass of the reactor room and the electrical equipment stack with rigid discs forming the floors and ceilings. The stability of the frame in the longitudinal direction is created by installing reinforced concrete braces 1 between the columns in each thermal unit and also vertical, metal cross couplings 2 (Fig 4-1).

The distances between the thermal and thermal -settling expansion joints are designated beginning with the conditions of the breakdown of the building into thermal units in accordance with the process requirements, and they must not exceed the values recommended by SNiP. Thus, a machine room 252 meters long is broken down into five thermal units.

The ends of the machine room are designed in metal, and the wind loads are taken by a wind truss installed at the service level (9.6 meters), and in the top section, by cross couplings with respect to the bottom chord of the ceiling trusses.

The ends of the reactor room are designed in prefabricated reinforced concrete; the frame of the transverse electrical equipment stacks is adjacent to them. The wind loads at the end of the reactor room which is erected over the end stacks are taken by horizontal couplings along the bottom chord of the ceiling trusses of the reactor room.

The machine room and the reactor room are covered with metal trusses, with length corresponding to the spans, with hinged support on the top chord. The machine room truss is made with a light and ventilation window (see Figure 4-2).

The roof of the machine room and the reactor room is made from prestressed reinforced concrete slabs on metal trusses; in the electrical device stack and the exhaust ventilation center it is made of reinforced concrete slabs on prefabricated reinforced concrete collar beams. The between floors of the electrical device stacks are assembled from prefabricated reinforced concrete slabs on prefabricated reinforced concrete collar beams.

In the machine room the floor or ceiling at the 0.0 level (see Figure 3-5) is made of prefabricated reinforced concrete ribbed slabs 3×3 meters, and at locations in the installation areas which take heavy loads, from solid reinforced concrete slabs supported on prefabricated reinforced concrete columns 400×400 mm in cross section made into foundations of the sleeve type. The entrance to the machine room is along a railroad track installed on the prefabricated reinforced concrete trestle designed for the weight of the transformer. The stability of the trestle in the longitudinal and transverse directions is designed using vertical metal of cross braces.

The basement retaining walls are made of prefabricated reinforced concrete blocks and prefabricated reinforced concrete foundation slabs. Under the entire basement there is a solid monolithic reinforced concrete slab on which a load of local sandy ground is packed to the concrete floor.

The foundations under the total units are designed in monolithic and prefabricated monolithic reinforced concrete, and under the auxiliary equipment, in monolithic and prefabricated reinforced concrete.

The outside walls of the main buildings made of reinforced concrete panels are 250 mm thick.

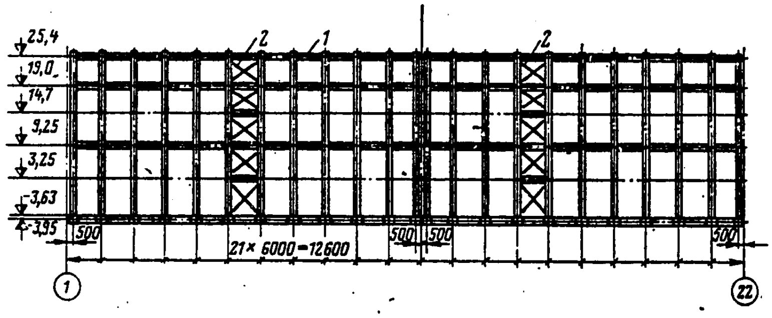


Figure 4-1. Diagram of longitudinal vertical couplings in the frame of the main building along row A.

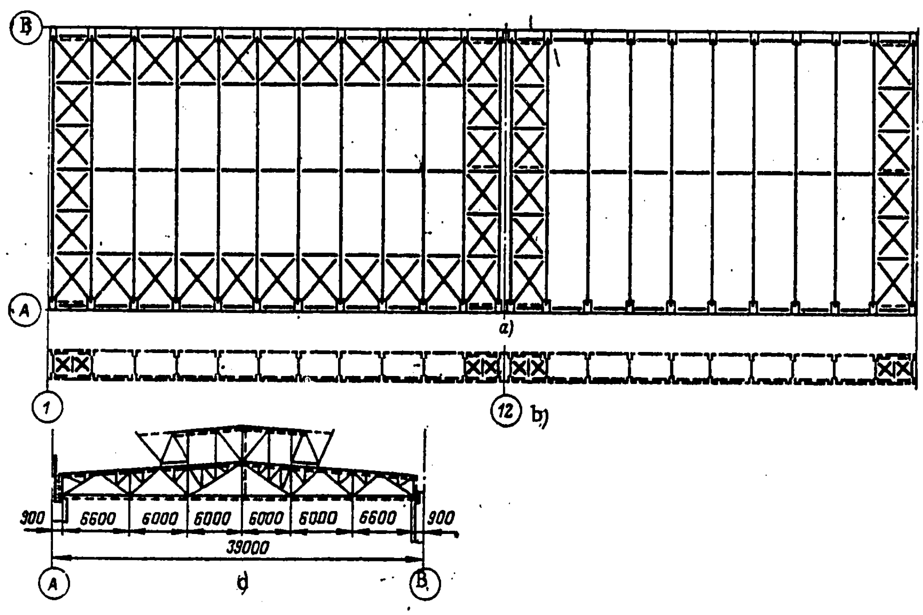


Figure 4-2. Roof of the machine room. a--plan with respect to the lower webs of the trusses. b--longitudinal section. c--transverse sector

For the supporting frame of the power units without VVER-440, the application of steel structural elements is limited to the trusses of the reactor room and the machine room, the tracks under the crane made of 14G2 steel and other small elements. The framings of the ends of the machine room, vertical and horizontal ties of the framing, the supporting metal structures, the service areas and other small elements are made of VSt3kp steel for welded structural elements. The corners of the electrical gear stacks are made of 14G2 and VSt3kp steel for welded structural elements in order to decrease the height of the ceilings on adjoining the collar beams on the same level.

The massive monolithic reinforced concrete structures of the reactor room which are built from the foundation to the 10.5-11.8 mark are a reliable foundation for the prefabricated, reinforced concrete framing (see Figure 3-5).

The wall and ceiling thicknesses of the reactor room are determined by the conditions of the biological shielding. The walls have complex configuration and a large number of built-in production parts, and they are designed in the prefabricated monolithic and monolithic reinforced concrete execution with reinforcing made of large packages of trusses.

The ceilings over the boxes of the steam generators and the main circulating pumps are designed from monolithic reinforced concrete with rigid reinforcing frames and truss packets.

The reactor room is made by the dropped pit method; therefore the structure of the base soil is not disturbed, and additional expenditures on its consolidation under the foundation slab are excluded. The wall of the dropped pit is covered on the outside with plaster asphalt hydroinsulation made of hot asphalt mastic protected by a layer of gunnite from mechanical effects when the pit is lowered.

The floors in the "dirty" facilities are made by pouring concrete on the structural elements. The slope of the floors in the direction of the collecting troughs is taken as 0.02 from the condition of drainage of the deactivating solutions. The troughs have slopes of 0.005 in the direction of the special sewage traps.

The special sewage lines are built in the body of the concrete slab with slopes of 0.01 from the drainage condition. The floors and the channels are covered with special anticorrosion covers.

All of the concrete or reinforced concrete and metal structural elements of the radioactive circuit, including the lining made of carbon steel are covered with special anticorrosion coatings.

All of the concrete, reinforced concrete and metal structures of the radioactive circuit, including the carbon steel lining, are coated with special enamels and paints depending on the radiation situation in the facilities and the requirements with respect to deactivation.

In order to provide for the service life of the structures, a number of measures are taken to protect the structural components of the "clean" facilities from corrosion.

The built-in metal parts in the reinforced concrete for attaching the panels are galvanized, and the remaining built-in parts are coated with anticorrosion grease.

In the presence of groundwater which is aggressive to concrete in all forms of cements in the nuclear power plant site at the level of setting the foundation footing of the basic structures (the main building, spetskorpus), hydraulic seal of the underground parts of the buildings is accomplished by using three layers of waterproofing material in a bitumen mastic. All of the outside surfaces of the structures which are underground are coated twice with bitumen. At the present time waterproofing material made of shaped polyethylene is used. The application of this type of waterproofing material improves its quality and sharply lowers the labor expenditures on the construction site.

Main Building of the Nuclear Power Plant with VVER-1000 Reactor

The structural designs of the main buildings with VVER-1000 and VVER-440 reactors have significant differences.

The reactor room of the nuclear power plant with the VVER-1000 reactor (see Figures 3-7 to 3-10) is placed in an independent space. The foundation slab of the reactor room 3 meters thick is made of monolithic reinforced concrete reinforced with spatial blocks. The reinforced concrete structures from the footing of the foundations laid to the 12.3 meter level form a rigid massive three-dimensional box on which the prestressed reinforced concrete shell of the reactor room is supported.

The walls of the spaces between the foundation slab and the ceiling slab at the 12.3 meter level are reinforced blocks with concrete faces with previously installed fittings for running service lines and pipes. The inside cavity of the walls (between the concreted faces) is filled with concrete after they are installed.

The ceiling slab at 12.3 meters is reinforced with sectional reinforcing blocks lined on the outside. The lining is used as a form.

The reactor pit is reinforced with three-dimensional blocks with metal lining. The end reinforcing in the reactor pit is designed to take an emergency pressure.

The walls of the sealed space above the 12.3 meter mark are designed for emergency loads, and they are made of steel cells, using the metal sheeting of the lining as the supporting reinforcing. In order to join the reinforcing in the walls and ceilings, a Perederiye joint is used.

For the structural elements of the reactor room, concrete type 200 is used, the specific weight of the concrete from the biological shielding conditions is no less than 2.2 tons/$m^3$. The supporting reinforcing is a periodic section type A-I, from 20 to 36 mm in diameter. The structural reinforcing is made of type A-III steel from 10 to 20 mm in diameter.

The lining of the reactor room is made of type 400 concrete with reinforcing by stressed bundles of high-strength, smooth rod 5 mm in diameter laid in polyethylene tubing 225 mm in diameter. The bundles are stressed by special jack with a force of 10 MN The injection of the channels is not provided for; in order to prevent corrosion the bundles are coated with special lubricating compounds.

The prestressing is determined beginning with the possible losses of tension during prolonged operation, but in spite of this fact, provision is made for the possibility of monitoring the tension of the reinforcing during the operating period and tightening of the bundles if necessary. In addition to the stressed bundles, the shell is reinforced with unstressed structural reinforcing to take the thermal forces and local stress concentrations.

The shell is made in the form of a cylinder joined to a flat bottom and covered with a dome. The radius of curvature of the dome is selected 1.5 times larger than the cylinder radius, for with this ratio of the radii, the vertical forces in the cylindrical part of the shell and arising with internal pressure in the dome can be first taken by the stressed reinforcing of one cross section. The height of the cylindrical part is 68 meters, the inside diameter of the cylindrical part is 45 meters. The thickness of the walls (1.2 meters) and the dome (1.0 meter) is taken from the biological shielding conditions, and the dimensions also satisfy the strength conditions.

The cylinder is coupled to the dome in the form of a ring in which the stress reinforcing is anchored. The cylinder is joined rigidly to the bottom, and on the inside the joint is reinforced with a reinforced concrete bracket.

For the cylindrical part of the shell, in contrast to the orthogonal reinforcing widely used in world practice, helicoid reinforcing is used in which the reinforcing bundles running opposite to each other along a helical line at an angle of 35°15' to the horizontal plane provide for creation of the necessary squeezing vertically and horizontally (Figure 4-3).

The dome is stressed by two groups of bunched reinforcing which are at an angle of 90° to each other in plan view. The trajectory of each bunch is in the plane perpendicular to the surface of the dome.

In order to insure a seal of the shell, provision is made for an inside metal lining used as the form during the concrete pouring operations. The lining is made of sheet carbon steel 8 mm thick protected from corrosion by aluminum plating with sealing of the pores with epoxy coating. The tightness of the seams is insured by special battens. The lining is attached to the concrete by angles welded to the sheet with anchor bolts.

The cylindrical part of the shell is erected to the entire height from large three-dimensional reinforced blocks weighing up to 20 tons, completely factory made with previously installed metal lining and process fittings.

The concrete pouring is done in a sliding form, for which a one-way form is constructed which provides for continuous operations along the entire perimeter.

For construction of the dome, a structural design has been developed with installation of a temporary top supporting arch permitting the dome to be erected independently of the bridge crane which installs the equipment. A circular installation bridge is suspended from the center of the arch (see Figure 4-4) which is designed to perform the welding and other construction-installation operations on the dome.

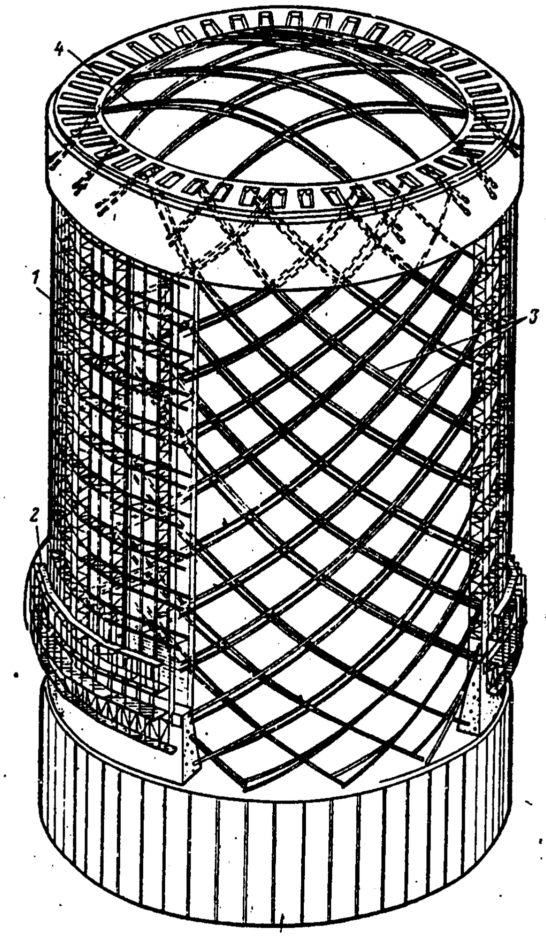


Figure 4-3. Diagram of the erection of the cylindrical part of the shell and location of the channel formers
1 -- reinforced framing; 2 -- sliding form; 3 -- polyethylene channel former of the cylindrical part; 4 -- polyethylene channel former of the dome.

The ends of the steel sections with lining which form a single dome after closure are supported on the same central support of the arch. The first layer of the dome is poured 350 mm thick. Then after laying the bunched reinforcing and the structural reinforcing, the dome is concreted to the entire thickness. All the operations of building and concreting the structural components of the reactor room are conducted in four stages (see Figure 4-5).

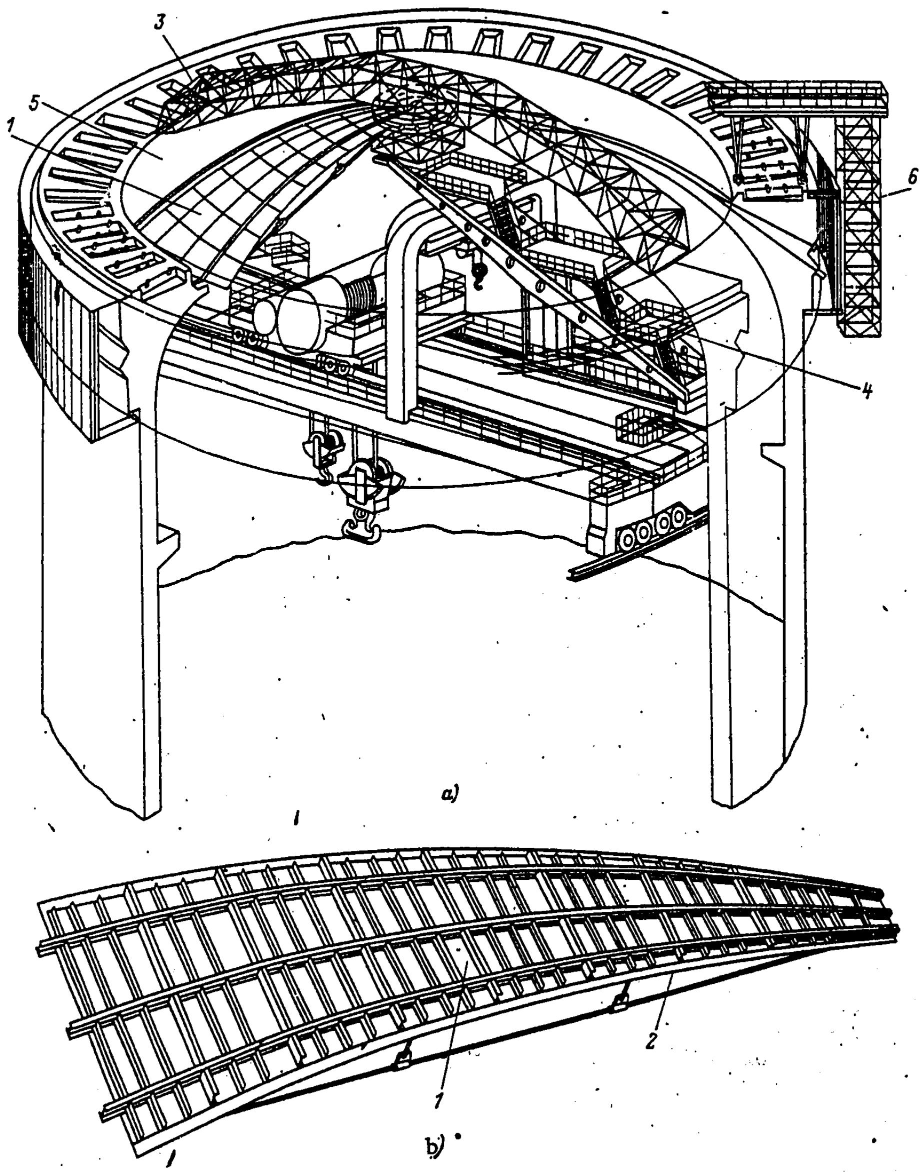


Figure 4-4. Schematic of the erection of the dome of a shell (a) and a fragment of a metal section (b).
1 -- metal section of the dome; 2 -- metal lining; 3 -- removable installation arch; 4 -- installation bridge; 5 -- reinforced concrete shell; 6 -- top manipulator

After concreting the shell, the bunched reinforcing stretched through the channel formers, and they are put under multistage group tension to a force of 10 MN. For mechanization of these operations special manipulators have been developed.

The shell is equipped with monitoring and measuring instruments to monitor its conditions and its operations during construction, for prestart-up testing and operation and maintenance later.

The machine room and the electrical device stacks are rectangular, 156×63 meters in plan. The supporting frame designed in metal is formed by transverse frame with 12 meter spacing in the longitudinal direction. The framing of the machine room is adjacent to the multistory electrical device stack. The stability of the building in the transverse direction is insured by the rigid frame of the stack. The stability of the frame in the longitudinal direction is created by vertical ties and bases between the columns.

The frame of the machine room and the electrical device stacks is made of the following types of steel: St.45 and 14G2; the chords and the supporting braces, trusses, and collar beams of the stack, the webs of the columns and the crane tracks are made of 14G2; and the remaining structural elements are made of VSt3ps steel.

The hinge-supported roof trusses of the machine room are taken in the trapezoidal shape with triangular lattice. The height of the halftrusses corresponds to the conditions of reinforced concrete dimensions. The trusses are made with a window.

The hanging facade wall of the machine room, the electrical device stack and the installation room of the spetskorpus from the 12.6 m mark and higher is made of three-layer wall panels with the application of steel sheet section. Inasmuch as the machine room has a light and ventilation window, the facades are designed with minimum necessary glazing which basically is provided at the service level and is justified by the ventilation requirement. The enclosure of the machine room to the 12.6 m mark is provided with respect to the inside face of the columns made of claydite concrete and light panels. All of the claydite concrete panels are faced with glass inlay.

The frame of the end of the machine room is made metallic with 12 meter spacing with a wind load truss constructed on the same level with the service areas f r the type of unit and the electrical devices stack.

The between floors of the electrical unit stack are made of standardized reinforced concrete, prestressed slabs of variable height with bent reinforcing strands. For the roofing, thermal panels are used 12 meters long made of polished steel sheets. The tracks under the crane are metal, cut from 14G2 steel. The floors at the 0.0 meter level of the machine room are made of prefabricated, ribbed reinforced concrete slabs 3.0×3.0 meters, and at the points of installing the platforms, from solid reinforced concrete slabs. The slabs are supported on columns built into the sleeve type foundations.

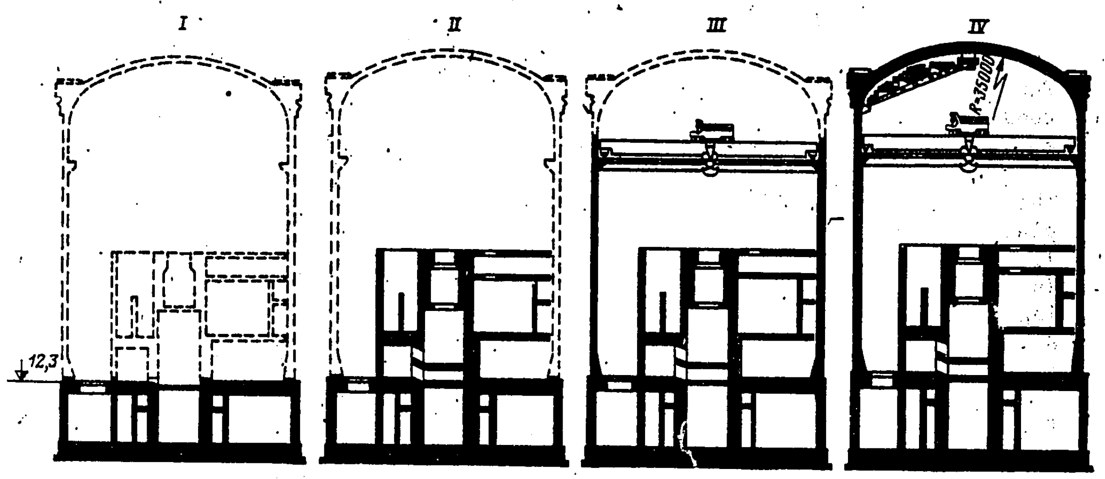


Figure 4-5. Diagram of the performance of construction operations when building the reactor room in stages

The foundations under the turbounit are designed from prefabricated monolithic reinforced concrete for auxiliary equipment -- monolithic and prefabricated reinforced concrete.

The retaining walls of the basement are made of standardized reinforced concrete prestressed panels.

In order to avoid nonuniform settling under unfavorable ground conditions, large-diameter drilled and driven piles are driven under the foundations of the machine room frame and the electrical unit stack and also under the turbounits. With aggressive groundwater, the piles must be made of concrete with increased density.

In order to improve the reliability of protection of the basement from groundwater flooding, in addition to the drainage, a solid reinforced concrete slab is laid, and bonded waterproofing material is installed.

Auxiliary Buildings

The spetskorpus of a nuclear power plant with VVER-440 reactor consists of two parts separated by the thermal-settling expansion joint, high -- specialized water and gas purification -- and underground -- special waste storage (Figure 4-6 and 4-7).

The underground part from the footing mark to 4.6 meters made of monolithic and prefabricated monolithic concrete and reinforced concrete forms a rigid box foundation serving as a reliable foundation for the higher structural elements. The above-ground part is made in the form of a prefabricated reinforced concrete frame from the ±0.0 mark and a stack between rows B and C. The spacing of the columns in the longitudinal direction is 6 meters. For the installation time the stability of the frame in the transverse direction is insured by the rigidity of the frame subassemblies of the framing stack, and in the longitudinal direction, by the vertical, cross mechanical ties.

During the operating period, the stability both in the longitudinal and transverse directions is created by rigid diaphragms formed by the reinforced concrete biological shielding walls.

The outside walls are made of reinforced concrete panels 250 mm thick.

The special waste storage, which is in the form of a rectangle in plan view is made of monolithic and prefabricated monolithic reinforced concrete, depending on the process requirements.

The tanks for storing active liquids are designed metal by the "container in container" principle in order to control random leaks of the main tank and simultaneously keep the active liquids from getting into the concrete.

The spetskorpus of a nuclear power plant with VVER-1000 reactor is a rectangle 60×84 meters in plan. The building is built to the 7.5-12.0 meter mark from prefabricated monolithic reinforced concrete; above, it is framed, in the form of a four-span frame with spans of 12 and 15 meters. In the longitudinal direction the column spacing is taken as 6 meters (Figures 4-8 and 4-9).

The frame columns are prefabricated reinforced concrete, and the roofing beams are metal. The internal structural elements, depending on the biological shielding requirements, the number of intersections of the process service life and continuation, are made of monolithic or prefabricated reinforced concrete. Reinforcing blocks with monolithized faces are used for the inside structural components (Figure 4-10).

The foundation of the spetskorpus is a solid foundation slab under which bonded waterproofing material is installed.

The sanitation and general services facility is a five-story building with basement and engineering level; its dimensions in plan are 36.0×36.0 meters, the story height is 4.2 meters, the column grid is 6.0×6.0 meters. It is connected to the main building by a crosswalk at the third-story level. The building of the sanitation and general services facility is frame type (Figure 4-11). The frame is made up of six-span, five-story prefabricated reinforced concrete frames tied in the longitudinal direction by braces and panels of the between floors. The transverse and longitudinal rigidity of the frame is realized by rigid reinforced concrete diaphragms. The frame columns are supported on the walls and columns of the basement part of the building which are executed in monolithic reinforced concrete. Under the solid foundation plate there is solid bonded waterproofing material.

The wall enclosure is designed from claydite concrete panels faced with glass inlay. The brick walls of the basement are lined with a "horn" type of ceramic tile. The window frames and sashes are made of aluminum alloy.

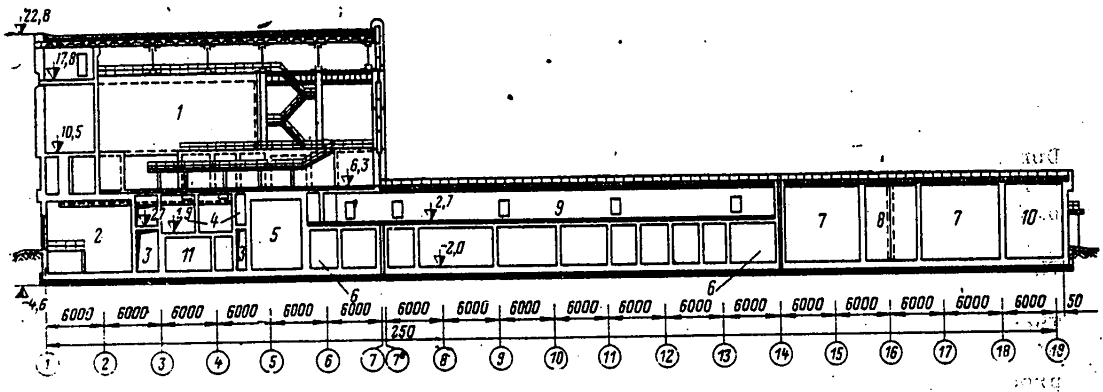

Figure 4-6. Spetskorpus of a nuclear power plant with VVER-440 reactor (section)
1 -- service room; 2 -- intake ventilation center; 3 -- service corridors for pipelines; 4 -- exhaust ventilation center; 5 -- adsorber; 6 -- ventilation chambers and trap water and condensate pumping station; 7 -- dirty condensate tank; 8 -- monitoring and measuring instruments facilities; 9 -- service facility; 10 -- boron concentrate tank; 11 -- dosimetric monitoring facility

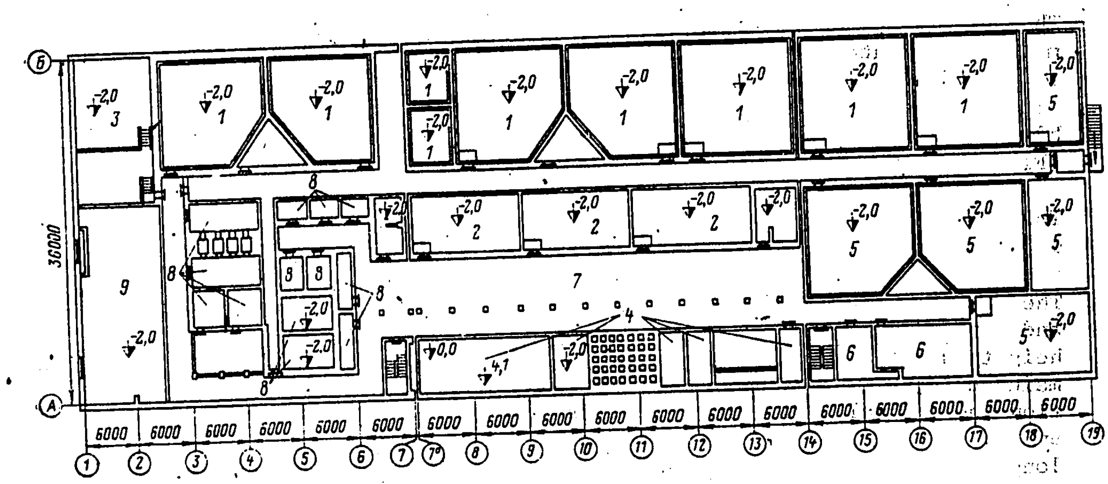

Figure 4-7. Spetskorpus of a nuclear power plant with VVER-440 reactor, plan at the 2.7 meter mark
1 -- facilities for storing liquid waste; 2 -- trap water tank facility; 3 -- "clean" concentrate pump facility; 4 -- facility for storing dry waste; 5 -- tank of "dirty" condensate and boron concentrate; 6 -- SVO installation; 7 -- service compartment; 8 -- exhaust ventilation center and gas purification; 9 -- intake ventilation center

Structural Design of the Radioactive Circuit Facilities

A characteristic feature of the walls and ceilings of the radioactive circuit facilities not calculated for emergency pressure is that their thickness is determined by physical calculation from the condition of providing biological shielding against radioactive radiation. The traditional calculation principle where the element cross section is determined from the condition of insuring the carrying capacity or limiting the deformations in this case is replaced by another principle -- for the given size of element cross section it is necessary by efficient reinforcing and proper consideration of all possible versions of operation of the system to achieve minimum consumption of the reinforcing per cubic meter of structural components. Since frequently the cross sectional dimensions given by physical calculation exceed those required by the condition of insuring the necessary strength, it is necessary to consider the operation of the lightly reinforced concrete.

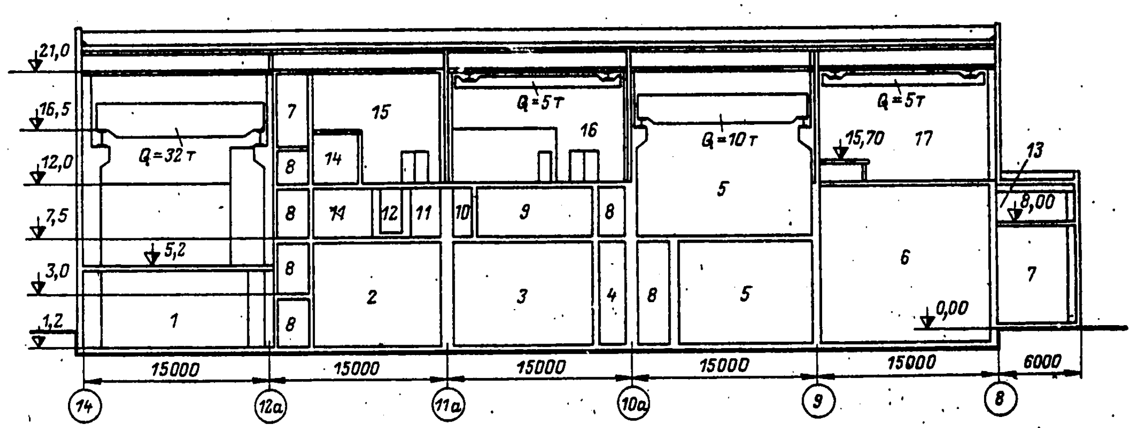


Figure 4-8. Spetskorpus of a nuclear power plant with VVER-1000 reactor (section)
1 -- area for fresh fuel containers and jackets; 2, 3 -- bottoms tank area; 4 -- air lift area; 5 -- "dirty" mechanical workshop; 6 -- "clean" condensate tanks and pumps facility; 7 -- special water purification compressor room; 8 -- corridors; 9 -- ventilation chamber; 10 -- "dirty" pipe service corridor; 11 -- ventilation system plenum area; 12 -- aerosol filter area; 13 -- reagent storage; 14 -- area for dosimetric monitoring of stack discharge; 15 -- exhaust ventilation center assembly room; 16 -- special water purification assembly room; 17 -- intake ventilation system assembly room.

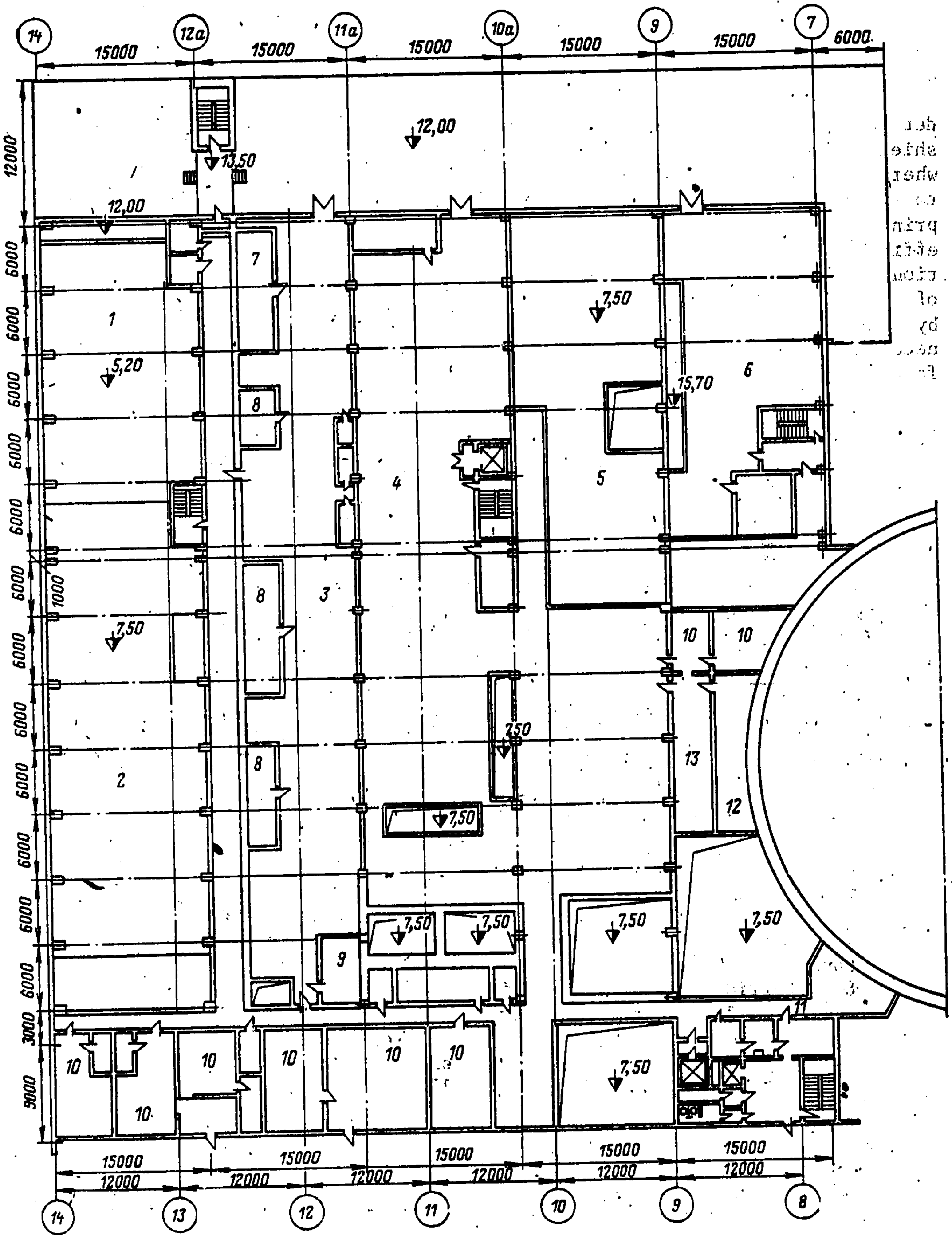


Figure 4-9. Spetskorpus of a nuclear power plant with VVER-1000 reactor, plan at the 12.0 meter level [See legend on following page]

[Legend for Figure 4-9]:
1 -- fresh fuel storage; 2 -- spent fuel container storage; 3 -- exhaust ventilation center assembly room; 4 -- special water purification assembly room; 5 -- "dirty" workshop; 6 -- intake ventilation center assembly room; 7 -- dosimetric monitoring facility; 8 -- fan facility; 9 -- gas borer facility; 10 -- laboratory; 11 -- washrooms; 12 -- pipeline shaft; 13 -- control panel

As the biological shielding of the radioactive circuit, at modern nuclear power plants ordinary reinforced concrete is used with a specific weight of 2.2 to 2.4 tons/$m^3$, and only in exceptional cases are heavy concretes of increased specific weight (3.6-4.2 tons/meter), cast iron protective plates, and so on used (for more details see Chapter 5).

The reinforced concrete enclosing structures of the radioactive circuit simultaneously perform the functions of the biological shielding of the bearing structures, and in individual cases, together with the metal lining they insure a seal of the radioactive circuit facilities with increased pressures and temperatures (in emergency situations).

The requirements of sealing the facilities and biological shielding lead to the fact that the cables, pipelines providing for the production process pass through the walls in special fittings installed in the walls before the concrete is poured. Also fittings are installed before pouring the concrete to fasten the service lines and the sealed doors and hatches.

The high cost of the stainless steel pipelines, electrotechnical and monitoring and measuring service lines, complexity of purifying the air in the radioactive circuit facilities gives rise to the necessity for maximum reduction of the size and, correspondingly, the volumes of the facilities. This leads to highly complex structural designs of the facilities, especially in a cylindrical shell.

The engineering and construction design of the structural elements of the radioactive circuit is presented in accordance with the appropriate SNiP.

From 100 to 150,000 $m^3$ of reinforced concrete are spent on the main facility of a modern powerful nuclear power plant, that is, 0.09-0.18 $m^3$/kilowatt. The basic proportion of the reinforced concrete consumed for the main facility of a nuclear power plant goes to the structural components of the radioactive circuit facilities. For the entire nuclear power plant complex, including the auxiliary structures, up to 250,000 $m^3$ of reinforced concrete or concrete are required.

For the construction design and construction of the biological shielding it is necessary to insure high quality of the concrete, for the presence of pits in the concrete can greatly reduce the shielding characteristics of the enclosing structures which depend on wall thickness.

In the design it is necessary insofar as possible to avoid structural components and subassemblies where the pouring of the concrete is difficult. At locations where the reinforcing and fittings accumulate, which are difficult of access for vibration, it is necessary to use mobile concrete mixes of increased plasticity. When performing the operation there must be rigid control of the pouring and vibration of the concrete mix, especially when it is poured behind the lining used in a form.

When designing the biological shielding it is necessary to know the degree of influence of cracks in the concrete on its shielding properties.

Ordinary reinforced concrete structures do not operate without cracks. By the conditions of preventing corrosion of the fittings in accordance with the norms, crack formation with a width of opening to 0.2 mm is permissible in these components.

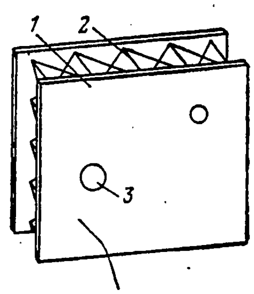


Figure 4-10. Reinforcing block with monolithic concrete faces.
1 -- concrete face; 2 -- bar trusses; 3 -- fixtures.

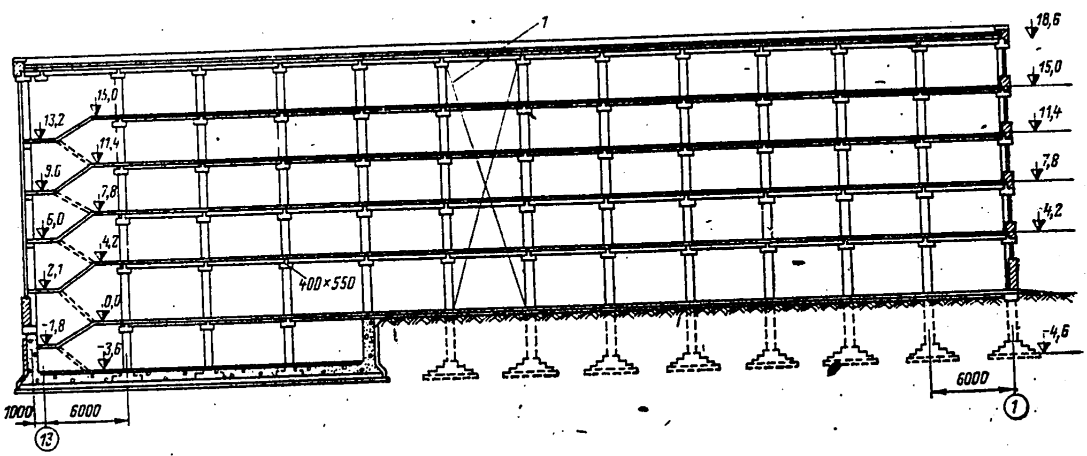


Figure 4-11. Frame of the sanitationand general services facility.
1 -- stiffening diaphragm

The studies of the properties of concrete biological shielding when it is under the effect of radioactive radiation demonstrated that ordinary broken (sawtooth) cracks in the concrete which do not permit direct leakage along the seam, screen out the radiation and in practice do not lower the shielding properties of the concrete. A phenomenon arises analogous to the passage of a light beam through broken slits.

On the basis of the research, the possibility of building biological shielding from reinforced concrete blocks (Figure 4-12) has been discovered, the thickness of which by comparison with shielding made of monolithic concrete is not increased. It is recommended that in these cases provision be made for vertical joints of the "dovetail" type with filling with ordinary concrete. The blocks are laid one on the other using ordinary mortar. The design of the joint in shielding made of heavy concrete must be substantiated by the corresponding calculation.

The reinforcing of reinforced concrete biological shielding is accomplished beginning with the condition of insuring the supporting capacity of the structural components under the effect of emergency loads, the rate of the higher structural components themselves, the weight of equipment during operation, maintenance and assembly and loads from the frame in the general framing system of the main facility, and so on.

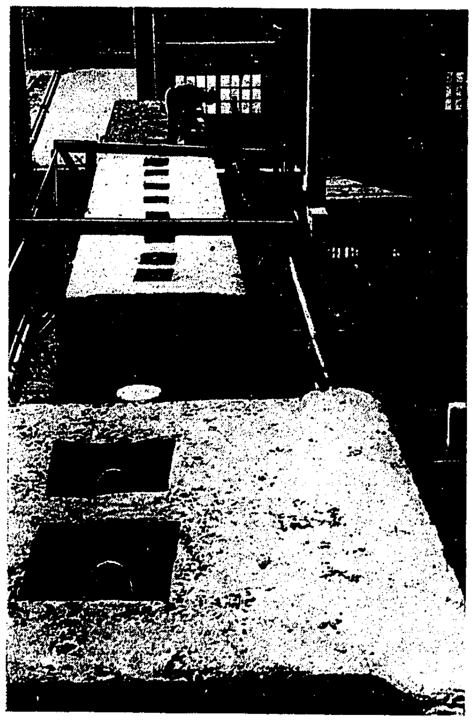

Figure 4-12. Prefabricated reinforced concrete blocks of biological shielding

Biological shielding used as the supporting structure can be divided into two categories. The first category includes biological shielding, the thickness of which determined by physical calculation exceeds the thickness required to insure supporting capacity of the structure and its reinforcing is not required by engineering design. This type of structure includes the lightly loaded walls and ceiling of a short span in facilities requiring increased radiation shielding.

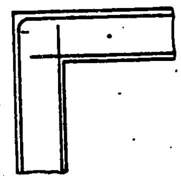

Figure 4-13. Diagram of proper reinforcing of a corner

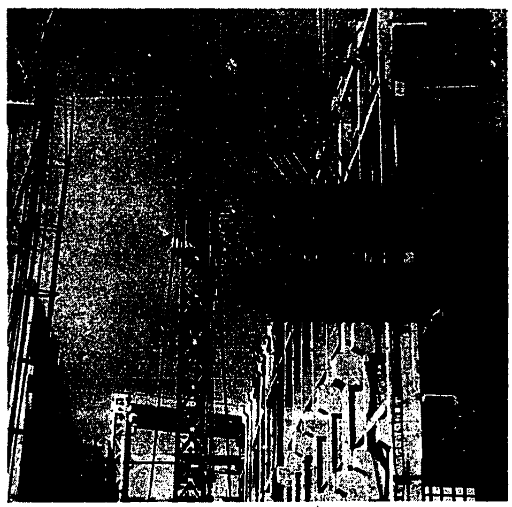

Figure 4-14. Reinforcing block (truss package) of a reactor room wall

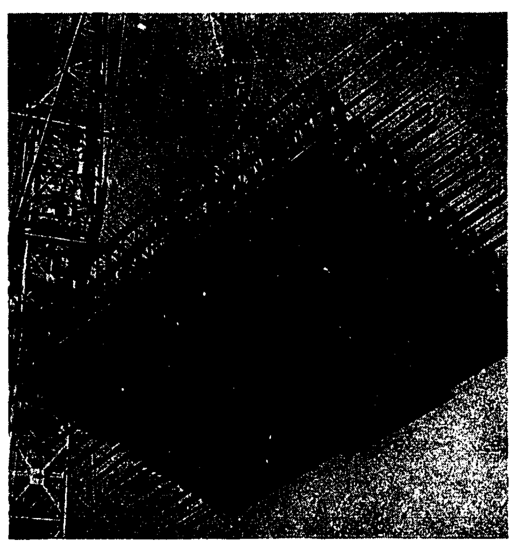

Figure 4-15. Reinforcing block (reinforcing frame) of the ceiling of the reactor room lined with sheet steel

The second category includes biological shielding, the thickness of which is completely used in the supporting structure and the reinforcing is required by calculation. This category includes the walls and ceilings of sealed radioactive circuit facilities designed for emergency pressure, the clean and dirty distillate tanks, the recharging and holding basins, large-span ceilings and floors, and so on.

The reinforcing of the structural components of the biological shielding in the first category is accomplished along the faces in two directions structurally to take the effects from the shrinkage of the concrete and changes in temperature. The reinforcing is usually of a periodic profile 12-16 mm in diameter with 200 mm spacing. During reinforcing, independently of whether the reinforcing is required by calculation or is installed structurally, it must be joined by a working joint and reliably accurate. This reinforcing principle is adopted to avoid stress concentration in the cross sections weakened by nonworking joint of the reinforcing and to prevent extraordinary opening of cracks from shrinkage and temperature in these locations.

In the case of reinforcing of corners, independently of whether the reinforcing is installed by the engineering design or structurally, the reinforcing rods are run into the adjacent structural components on the inside corners and they are joined continuously on the outside corners (Figure 4-13). This rule must be observed for reinforcing in any direction for both walls and ceilings and floors.

In order to facilitate the installation of the reinforcing of the structural components of the primary circuit the walls and the ceilings and floors can be reinforced by supporting truss packets and supporting reinforcing framing.

For formation of the truss packets the reinforcing required in the reinforced concrete structural component is joined into a spatial supporting block which is created by vertical and horizontal bar trusses with cross lattice. Here an effort is made to reduce the additional metal consumption to a minimum. The truss packets of the walls are depicted in Figure 4-14.

The reinforcing frames of the walls and ceilings are reinforcing blocks to which the form panels or metal lining used as the form are attached (Figure 4-15). Depending on the thickness of the floor or ceiling, the reinforcing frames are made either from bar trusses or from rolled metal trusses. The truss metal is considered as rigid reinforcing when calculating the reinforced concrete floors and ceilings.

If the reinforcing is required by calculation, then the truss packets of the walls are joined to each other by welding through an insert, the structural reinforcing is dovetailed or joined by superposed grids. The Perederiye loop joint has found broad application for joining the calculated reinforcing of the truss packages of the walls and the reinforcing frames of foundation slabs and ceilings and floors. This joint sharply reduces the amount of welding required at the construction site.

Engineering Design Elements of the Structural Components of the Main Structure

When calculating the structural design of the main structure, it is necessary correctly to estimate the operation of all of its component parts in the overall system of the building during all periods of construction, installation, assembly, operation and maintenance. Here the most unfavorable, but possible combinations of loads on the structural components must be taken into account. An analysis must be made of the operation of the entire system as a whole. The analysis of the operation of the entire structure for special combinations of loads, during emergencies and disastrous natural phenomena such as hurricanes, earthquakes, and so on, requires fixed attention.

Properly selected design diagrams of the structure are the guarantee of economical and safe operation of the entire complex of nuclear power plant structures.

The method of construction must also be considered when evaluating the operation for the project in its various phases of erection, when selecting its engineering design diagrams and, of course, when constructing its elements.

When constructing the nuclear power plant it is necessary to begin with the most improved methods of performing the construction operations which will insure high quality of the structural components and minimum expenditures on erecting them. When estimating the efficiency of the choice of one system or another of executing the structural components, primary attention must be given to reducing the labor expenditures at the building site.

Rated Design Diagrams

In order to calculate the structure, it is necessary to replace it by a design diagram. The design diagrams must be the most exact picture possible of distribution of forces and displacements of the elements for any possible combinations of loads. For each phase of operation of the structure both during construction and during operation and maintenance, its correspondence to the selected design diagrams must be checked. The more complicated building, the greater the number of versions in the design diagrams that must be considered in order to reflect its actual condition in various phases of erection, operation and maintenance.

The degree of accuracy in performing the calculations must be reasonable considering the fact that when selecting the engineering design diagrams some simplifications are introduced by comparison with actual operation of the structure. The greatest attention must be given to consideration of the spatial operation of the structural components, the interaction of the elements in plan view and with respect to altitude. This specially pertains to calculating the reinforced concrete structural components of the radioactive circuit.

When building, operating and maintaining the structures it is necessary to know the rated design diagrams by which the structural components were calculated and not permit deviations from them. Any deviations, the necessity for which has arisen during construction, operation or maintenance, must be agreed on with the designers.

This requirement arises from the fact that the variations in the structural components, for example, exclusion of individual elements of the frame, organization of openings in the wall or the ceiling for assembly and the dismantling of equipment not provided for by the design diagram can change the static system of the structure, and an emergency can arise under loads less than provided for in the design.

Geometric ˜nvariability of Structures

The structural components must provide geometric invariability, stability of the structure for any possible combinations of loads on it as a whole or on individual elements. Failure to satisfy this requirement during the design and construction of the structure can lead to serious emergencies.

Usually geometric invariability of structures is provided by the construction of rigid vertical and horizontal discs which can be formed by reinforced concrete monolithic or prefabricated (monolithized) structural components in the plane of the walls and the floors and ceilings or using metal ties provided between the frame columns, and in the plane of the bottom chords of the roof trusses. The ties can be installed temporarily to insure invariability of the system for the assembly period before erection of the monolithic reinforced concrete massifs or for the entire service life of the structure.

The system of ties and rigid discs must provide for successive transfer of forces from the point of application of the load to the foundations of the building. It is necessary to see that this is along the shortest path.

In individual cases the transverse and longitudinal stability of the building can be insured by rigid joints of the building elements without installing additional ties. In all cases, insurance of stability of the building must be checked by special calculations considering all phases of the construction and erection of the structure.

Rated Design Diagrams of the Frame of the Primary Structure. When compiling the rated design diagrams of the frame of the primary structure, the reactor section block is taken as a rigid disc, for its rigidity is incommensurately higher than the rigidity of the frame elements as a result of transverse walls, floors and ceilings.

If during the period of erection of the building, according to the construction procedures, the reactor section block cannot be considered in the operation of the frame (for example, it is necessary at some time to pass a construction crane between the reactor section and machine room), it is necessary to install temporary metal ties in the frame of the machine room or, checking by calculation, to reduce the loads of the frame by limiting the lifting capacity of the bridge cranes in the machine room or not hanging the wall panels along row A in order to decrease the wind load.

The use of the biological shielding block of the reactor room as a component part of the complex of supporting structures of the principal structure is interesting to trace in the example of designing the structural components of the principal structures of the first three stages of the Novovoronezh Nuclear Power Plant. Whereas during the operation and maintenance period the reactor room block in the structures of all three phases of the electric power plant is considered as a rigid disc, the problem of using the biological shielding structures in the operation of the frame in the first phase of construction was solved differently (see Figure 4-1).

In the first phase (Figure 4-16, a) the massive monolithic reinforced concrete structural components of the reactor room were erected by construction cranes to the 17.5 meter level; then the reinforced concrete frame was installed on them on which the bridge crane was mounted. The erecting loads from the crane were transmitted through the frame columns to the reinforced concrete block.

In the second phase (Figure 4-16, b) a prefabricated reinforced concrete frame was installed onthe foundation plate to the entire height of the building. One of the bridge cranes with 30-ton capacity was supported on the frame. After installation of the frame, the roof and wall enclosures were installed. The basic concrete work of erecting the monolithic reinforced concrete structural components of the biological shielding was done inside the building using the bridge cranes. The rated design diagram of the frame during erection differed sharply from the rated design diagram during operation, for in the first phase of construction the primary circuit block did not participate in the work of the frame. The frame columns were subsequently concreted in, and they became part of the monolithic mass of the biological shielding of the reactor section.

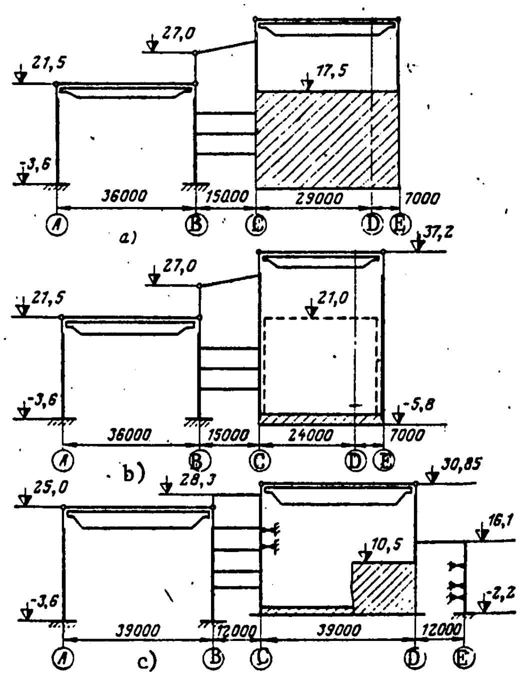


Figure 4-16. Rated design diagrams for the frame of the principal structure of the Novovoronezh Nuclear Power Plant during construction

In the third phase (Figure 4-16, c) the decision was made to install the frame columns on the foundation plate only along row C for the possibility of erecting the longitudinal electrical equipment stack independently of the structural design of the reactor section. The wall of row E, in view of the high saturation with fittings, was executed in monolithic reinforced concrete. The rated design diagram of the frame during erection was found to be intermediate between the rated design diagrams of the first and second phases of the electric power plant. The rated design diagram of the frame is depicted in Figure 4-17 for operation of the power unit with the VVER-440 reactor.

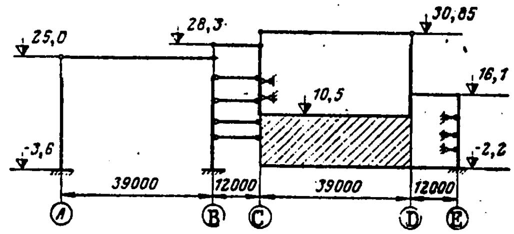


Figure 4-17. Rated design diagram of the frame of the main structure of a nuclear power plant with VVER-440 reactor during operation and maintenance

When solving the investigated erection diagrams, two principles were advanced: the first was maximum economy of the material, total use of the bearing capacity of the structural components in all phases of construction and erection; the second was maximum use of the operating lift machinery during the construction and installation period, an effort at maximum short times for beginning of installation and conduct of it in the closed facility.

Another structural solution was then adopted for the nuclear electric power plants with VVER-440 reactor: the prefabricated reinforced concrete columsn of the framing do not pass through the biological shielding walls, but are supported on them. For acceleration of the startup of the bridge crane the entire reactor room block is not erected, but only the walls under the columns. When necessary the lift capacity of the bridge crane is limited for the period before erection of all of the structural components of the reactor section, insuring restraint of its framing stanchions (Figure 4-18)

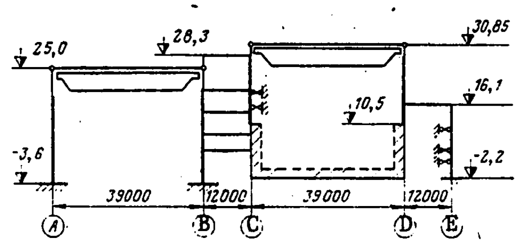


Figure 4-18. Rated design diagram of the frame of the primary structure of the nuclear power plant with VVER-440 reactor during the construction period

Seismic Effects. When calculating the structural components of a nuclear power plant it is necessary to consider seismic effects. In order to insure the required degree of reliability and also to achieve the best economic characteristic of nuclear power plants located in seismically active regions, the equipment, the process systems, the monitoring and control systems and also the production buildings and structures are classified by the attributes of their participation in insuring radiation safety and reliable operation of the nuclear power plant.

The equipment and the systems of a nuclear power plant are divided into three groups with respect to earthquakeproofness:

Group I includes the systems, machinery, instruments, electrical equipment, control panels, cable and pipeline corridors, and so on, the purpose of which is connected with insuring radiation safety in emergency situations. This group includes the elements, systems and devices, damage to which can lead to an inadmissible increase in the oxygen activity yield and also the elements, systems and devices containing highly active media;

Group II includes the systems, equipment and devices, the failure or destruction of which will lead to fast (no more than a few hours) curtailment of the electric power generation process and also fire-hazardous devices and systems (categories A, B and C with respect to fire hazard), not entering into group I;

Group III includes equipment, systems and devices not entering into groups I and II.

In accordance with the classification of the process systems and equipment, three categories of earthquakeproofness of buildings and structures for production purposes are defined:

Category I includes the buildings and structures in which the process system and devices of group I are located (the means of insuring radiation safety, emergency shutdown, shutdown cooling and removal of residual heat releases from the reactor, the system for normal operation with active coolant or live steam to the cutoff elements inclusively, and so on);

Category II includes the buildings and structures in which the process systems and equipment of group II are located (the turbounit, the normal blowdown and makeup of the system primary circuit, the stationary oil and liquid fuel storage, the ventilation types, and so on);

Category III includes buildings and structures in which the process systems and equipment of group III are located (the auxiliary boiler room, acetylene generator, the combined auxiliary structure, and so on).

The structural components of a nuclear power plant belonging to category I are designed for seismic effects from an earthquake with a calculated probability of once in 10,000 years.

Since emergencies connected with rupture of the pipelines can be caused by earthquakes, buildings and structures of category I are designed for the joint effect of loads arising as a result of a maximum earthquake, and loads (mechanical and thermal) caused by the appearance of a "large" leak.

The structural components of a nuclear power plant are designed for seismic effects in accordance with SNiP II-A.12-69.

When determining the calculated seismicity of the region in which the nuclear power plant is being built, it is necessary to consider the possibility of changes in the background seismicity of the region as a result of consideration of the specific conditions of the nuclear power plant building site -- the microseismic regionalization.

Emergency Loads. In connection with increased requirements with respect to insuring safety of the nuclear power plant, the localization of the products of any possible emergency must take place within the limits of the sealed circuit. In accordance with the existing construction norms, the structures enclosing the radioactive circuit must be designed for the effect of all factors for maximum possible emergency (MV-A) and the dynamic forces arising in this case.

During normal operations of a nuclear power plant the pressure in the process circuit and the coolant temperature greatly exceed the pressure and temperature in the facility (the coolant parameters are determined by the type of reactor). In case of emergency, the active coolant escapes into the sealed facilities where the pressure and temperature rise sharply. Therefore when calculating the structural components it is necessary to consider the dynamics of the process of escape of the coolant accompanied by a change in the designed parameters in the radioactive circuit facilities. In the case of high pressure in the circuit (for example, a pressure in the primary circuit of the power unit with VVER-1000 reactor is 16M-Pa) in case of an instantaneous rupture of a main circulating line, a shock wave will occur. Jets of coolant in different phases under pressure can act on the surrounding structures; pipes and fittings can break, there can be so-called "flying objects," the ends of the broken pipe can move in any direction under the effect of the jet forces on escape of the coolant (with load on the stationary anchor support of the pipeline and, correspondingly, on the structural component in which the support is fitted, rises), the jet of coolant from the end of the broken pipe can be under pressure in any direction: toward the floor, the walls or the ceiling.

As the coolant escapes from the process circuit the pressure rises in the sealed facilities, depending on the type of coolant, its parameters and the volume of the facilities into which the coolant escapes. In order to lower the emergency pressure of the steam-air mixture in the sealed circuit facilities, special steam condensation units are used: bubblers, sprinkling systems. For the fifth power unit of the Novovoronezh Nuclear Power Plant the designed emergency pressure in the protective envelope of the reactor considering operation of the sprinkler systems was 0.4MPa.

Considering the radioactivity of the coolant, high requirements are imposed on the seal of the facilities and, correspondingly, on the structural components providing the seal. They must be designed for the most unfavorable combination of emergency and operating loads and unconditionally insure seal of the radioactive circuit facilities. The structure is calculated for dynamic short-term effects of a shock wave, the escaping jet of coolant, the jet forces on the pipeline supports, a sharp rise in temperature in the facilities and the effect of steady increased pressure and increased temperatures in a sealed volume.

On the basis of an analysis of the course of the dynamic processes during an emergency with time, it is necessary to select the calculated load combinations correctly. Since the calculation is performed for a low-probability emergency, excessive margins leading to overconsumption of materials are not necessary.

The effect of the emergency loads in accordance with the SNiP is taken into account in combination with the constantly operating loads from the weight of the structures, basins, equipment, and so on themselves. The overload coefficients in this case are assumed according to SNiP for special combinations of loads.

If an emergency can arise as a result of external effects such as an earthquake, a blast wave, possible combinations with emergency loads are considered in the calculation.

The structural components are checked for the effect of flying objects which first of all should not destroy the seal of the shielding structures. Since the seal of the reinforced concrete structures is provided by a metal lining, protection of the lining from flying objects must be provided.

In the practice of calculating emergency loads on the structural components of the radioactive circuit, there are still no special norms; the Instructions for Designing Mine Shelters (SN-453-73) are used. According to these instructions, when calculating the shielding structures for consideration in the dynamic effects, the following coefficients of dynamic reinforcing of the material $K_y$ are assumed, which increase the design resistance of the building materials:

| | |
|---|---|
| For concrete and rock masonry | 1.2 |
| For rolled steel sheet and section | 1.4 |
| For stretched longitudinal, transverse and bent reinforcing, classes A-I, A-II, A-III (for calculation for bending and transverse force) | 1.3 |
| For compressed reinforcing of all classes, stretched longitudinal, transverse and bent, classes A-IV, A-V, A-VI and reinforced by drawing or thermally | 1.0 |

The dynamic resistance of the material when designing the structural components for a shock wave is taken according to the corresponding chapters of the SNiP considering the reinforcing coefficient $K_y$.

The structural components of the reinforced concrete biological shielding inside the sealed circuit are designed for an emergency pressure gradient, shock wave, the effect of a coolant jet and the jet forces from rupture of pipelines.

The calculated emergency pressure gradients for the internal facilities of the reactor room of the VVER-1000 were taken as 0.17, 0.03 and 0.01 MPa depending on their remoteness from the possible place of rupture of a pipe.

The calculation for the shock wave is made in accordance with the Instructions for Designing Structural Components to Take Pulsed Loads [36].

It is not necessary to consider the simultaneous effect of the shock wave and the calculated emergency pressure on the structural components, for they do not coincide with respect to time.

The load on the structural component from the effect of the jets depends on the type of coolant, its temperature and pressure in the circuit and the distance of the structural component from the possible point of rupture. The proposed rupture of a pipeline can take place at any point; therefore the distance is determined from the calculated structural component to the nearest high-pressure line. The load on the structure from the coolant jet $q_{jet}$ is defined by the formula

$$q_{jet} = PF_{pipe}/F_{jet},$$

where P is the calculated coolant pressure in the circuit; $F_{pipe}$ is the cross sectional area of the coolant pipe; $F_{jet}$ is the area of effect of the coolant jet:

$$F_{jet} = \pi(D_y+2\ell \sin \alpha)/4;$$

here $D_y$ is the high-pressure pipe diameter; $\alpha$ is the angle of dispersion of the coolant on escape; $\ell$ is the distance from the line to the structural element.

Thermal Effects. During the normal operation, the temperature in the radioactive circuit facilities is determined by the heat releases of the process equipment and lines with the coolant and also the adopted ventilation systems. The manned and unmanned facilities can border on each other; therefore temperature gradients will arise on the surfaces of the walls and the floors and ceilings of these facilities. Thus, the temperature in an unmanned facility can reach 60-80°C, and the temperature in the adjacent manned facility will remain at a level of +20°C. For walls and floors and ceilings which border on the outside air, the designed temperature gradient increases, for the minimum winter temperature of the outside air must be considered. In this case the temperature gradient can exceed 100°C.

In emergencies when coolant escapes, the temperature in the facility can rise to +150°C and, correspondingly, the temperature difference on the surfaces of the elements can reach 170-180°C.

Ordinary concrete subjected to alternate cooling and heating during operations can be heated to 200°C, and in the structural components operating under constant heating conditions, to 250-300°C with corresponding loss of strength.

During normal prolonged operation at steady temperatures in the facilities and correspondingly constant thermal flux the forces from nonuniform heating will be low or will disappear entirely as a result of the development of creep deformations in the concrete. In the case of a sufficiently fast drop in temperature in the facilities when the power unit is shut down after prolonged operation a temperature gradient arises in the structural components in the opposite direction. In this case the designed characteristics of the concrete and the reinforcing are taken without considering creep.

The calculation for the temperature of the reinforced concrete elements is made in accordance with the structural mechanics rules, but considering that the rigidity of the cross sections depends on the elastic-plastic properties of the concrete and the reinforcing [35, 60].

The calculation of temperature effects is discussed in [35, 77].

When heating, the chemically unbound water is evaporated out of the concrete; therefore the specific weight of the concrete in the dry state decreases on the average from 100 $kg/m^3$, and on heating above 400°C, by 200 $kg/m^3$. Therefore it is necessary when calculating reinforced concrete structural components of biological shielding against radioactive radiation to consider the possible decrease in specific weight as a result of drying out of the concrete.

Spatial Operation of the Structural Elements. When designing the structural components of the radioactive circuit facilities the wall, ceiling and floor thicknesses must be calculated considering the maximum use of the material of the biological shielding, that is, it is necessary to strive to see that the biological shielding material is not only a radiation shield, but also a bearing structure participating in the overall operation of the structure.

The structural components of the radioactive circuit facilities usually are horizontal and vertical planes which form spatial, multibay and multistory boxes. When designing them it is necessary to consider the loads from the weight of the structural components themselves. It is also necessary to check the spatial box with all floors, ceilings and diaphragms for joint operation and to see that the corridors and openings for equipment do not diminish the bearing capacity of the supporting structures to an inadmissible amount. Since the load from the weight in a multistory reinforced concrete box increases from top to bottom, in all horizontal cross sections the area of the bearing structures must be correspondingly sufficient to transfer the load.

At the beginning of the design work it is necessary to know the configuration of the structure and plan view and with respect to height, the load from equipment, the location of basins and tanks with water, the facilities designed for pressure under emergency conditions, the required thicknesses of the structural components from the biological shielding conditions, and so on.

Special attention must be given to the structural design of the bottom facilities, for their vertical walls, and in some cases, in the case of unfortunate layouts, the floors and ceilings experience enormous loads from the structures above.

Consideration of the three-dimensional operation of monolithic reinforced concrete structures of biological shielding of the radioactive circuit facilities will be investigated in the following example.

It is necessary to calculate the structural design of the radioactive circuit facilities depicted in Figure 4-19. This is a two-story building elongated in the plan view. The walls and the floors and ceilings are monolithic reinforced concrete, their thickness has been determined from the biological shielding conditions. The central wall of the second floor does not coincide with the longitudinal walls of the lower floor.

If we do not consider the three-dimensional operatio of the structure, that is, we do not consider the operation of the transverse walls of the second story, the calculation is performed by the diagram presented in Figure 4-20, a in one plane considering the gradual involvement of the entire structure level by level in operation as it is erected. After erection of the floor-ceiling at the 5.0 meter

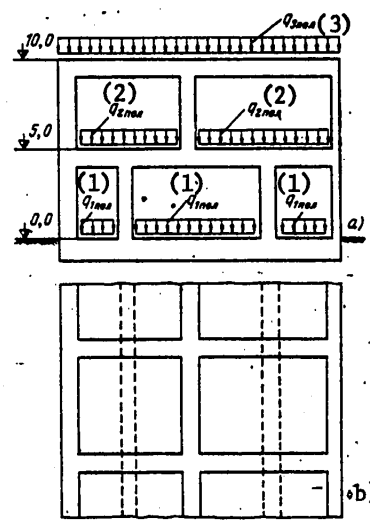


Figure 4-19. Structural diagram of the radioactive circuit facility. a -- section; b -- plan; $q_{1use}$, $q_{2use}$, $q_{3use}$ is the useful uniformly distributed load on the floor or ceiling.

Key:
1. $q_{1use}$; 2. $q_{2use}$; 3. $q_{3use}$

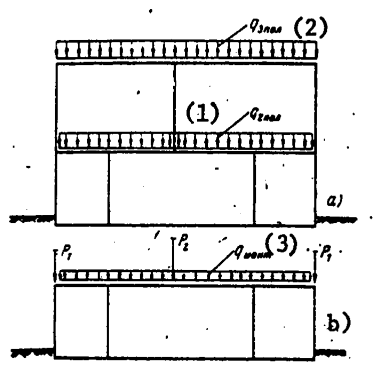


Figure 4-20. Rated design diagrams of the structural elements of a building (see Figure 4-19).
a -- cross section; b -- floor and ceiling at the 5.0 meter level during erection; $q_{erect}$ is the uniformly distributed erection load when building the walls and the floor-ceiling of the second story, $P_1$, $P_2$ are the loads from the weight of the second-story structures and the erection load for the floor-ceiling of the second story.

Key:
1. $q_{2use}$; 2. $q_{3use}$; 3. $q_{erect}$

level and the required setting time of the concrete, it is possible, taking the structures of the lower floor as a braceless truss, to consider it for the entire weight of the next floor. In the case of multistory building it is possible to consider each level in this way. After erection of the entire building, the two-story framing structure considering involvement of the entire system in operation is considered for the operating and emergency loads in the given case.

In the presence in the structure of transverse walls supported on longitudinal walls which in turn transfer the load directly to the ground, it is necessary to consider them in the calculation. In this case the transverse walls are beam-walls. In the rated design diagrams of the floor-ceiling of the second story at the 5.0 meter level the upper beam-walls are considered as the floor-ceiling supports, and the floor-ceiling and the beam-walls are reinforced accordingly.

When calculating large-span ceiling with respect to the lower supports, the walls of the biological shielding higher up can greatly facilitate its operation for operating loads. Thus, consideration of the upper walls in the investigated example permits the floor-ceiling at the 5.0 meter level to be calculated as supported along the faces and correspondingly to distribute the reinforcing with respect to two directions, which is especially important for long-span floor-ceilings. Considering the operation of the walls higher up offers the possibility if necessary to organize openings in the floor-ceiling and the lower walls. The reinforcing of the floor-ceilings, walls and their joints is accomplished in accordance with the selected rated design diagrams which must be reflected in the drawings. Attention must be given to checking the bearing capacity of the structural elements of the buildings during their erection. Thus, the floor-ceiling at the 5.0 meter level must be checked for the force from the weight of the wet concrete of the structures higher up. The rated design diagram for the erection period of the structure is shown in Figure 4-20, b.

The total load of the floor-ceiling in this case will be made up of loads from the weight of the walls, floors and ceilings above and the loads arising during construction and erection. The load from the central wall of the second floor must be taken considering its own weight and the weight of the wet concrete of the next floor-ceiling.

# Chapter 6. Organization and Technology of Nuclear Power Plant Construction

## 6-1. Organization of Construction

### Basic Principles of Organizing Construction

The improvement of the efficiency and quality of construction reflects technical progress in the branch. The primary areas of technical progress in nuclear power plant construction under modern conditions are the following:

improvement of the designs, conversion to the construction of series nuclear power plants;

the development of construction from prefabricated structural elements, an increase in their degree of completion at the plant, and the application of new, advanced structural elements and materials;

the development of a construction industry base;

improvement of all-around mechanization;

improvement of the technology of construction-installation processes and operations;

application and improvement of flow methods of construction-installation work;

the development of specialization of the construction-installation organizations, advanced methods of labor;

improvement of the new system of planning and economic incentives;

improvement of the construction-installation operations control systems;

introduction of an all-around operations quality control system.

These areas are closely interrelated and mutually dependent. The solution of the practical problems of improving construction in the area of organization and technology is being found considering this interrelation.

Structure of Contract Operations

The construction-installation operations at a nuclear power plant by agreements with the clients are performed by general contractors who use specialized subcontracting organizations. The subdivisions of the general contractor for the construction of the majority of nuclear power plants are directed by the All-Union "Soyuzatomenergostroy" Association of the USSR Ministry of Power Engineering. The general contracting organizations perform a large volume of the industrial construction work by their own forces (more than half of the total volume). The erection of the structural components and the earthwork are done by specialized subdivisions of this association. In order to carry out the special operations, subcontract organizations of the USSR Ministry of Power Engineering are used (chemical protection, waterproofing, hydromechanization and other operations) and also other ministries (outside railroads and long roads for motor vehicles, gas lines, elevators, and so on). In the construction of housing the general contractor, as a rule, performs all of the zero level operations and brick construction. The "Soyuzenergozhilstroy" Association which is part of the "Soyuzatomenergostroy" Association acts as a subcontractor in the construction and acceptance for operation of the aboveground part of the prefabricated housing.

For installation of the process equipment the general contractor calls on the Glavteploenergomontazh which installs the thermomechanical equipment, the Glavelektromontazh which performs all of the operations involved in wiring and installing the electrotechnical equipment, the monitoring and measuring instruments and automation, and the All-Union "Soyuzenergozashchita" Association which provides thermal insulation and chemical protection. Thus, all of the operations involved in installing the process equipment are performed by specialized subcontracting organizations of the USSR Ministry of Power Engineering. The interrelations of the general contractor and the subcontracting organizations are regulated by the contract rules.

The grant-receiving body-client of the majority of nuclear power plants is the management of the power plants under construction. The management boards are subordinate to the All-Union Industrial Association "Soyuzatomenergo" of the USSR Ministry of Power Engineering. An obligation of the client is provision of forms and reports, equipment, financing, acceptance of work performed and acceptance of the projects for operation. The client receives the technical forms and reports from the design organization and transmits them to the general contractor with the "in production" stamp. "Soyuzatomenergo" as the client plans the construction of the nuclear power plant, monitors the technical specifications for delivery of equipment, trains the operating personnel, provides for the operation of existing nuclear power plants. The adjustment operations are performed under the supervision of the management of the nuclear power plant by specialized institutes and organizations.

The process equipment is ordered by the Glavenergokomplekt by the specifications of the design organizations and the technical specifications agreed on with the supplier plant and the clients.

Material-Technical Base of Construction

The system of enterprises and facilities of the construction organizations of the USSR Ministry of Power Engineering and also branches of industry and transportation servicing construction is common to all power engineering construction, including nuclear power plants. The material-technical base of the USSR Ministry of Power Engineering is divided into four groups:

1) the enterprises of the industrial associations and main administrations;

2) enterprises and facilities of the construction-installation associations and main administrations on an independent budget;

3) subsidiary and auxiliary enterprises and facilities on the budget or leased by the construction organizations, including at the construction bases;

4) machines, machinery, transportation means forming the fixed capital of the construction organizations.

The construction of enterprises in the first and second groups, as a rule, is financed from the capital investments in the construction industry or in power engineering. The subsidiary and auxiliary enterprises are built at the expense of the means indicated in Chapter 8 of the summary estimate for the construction of power engineering and other projects.

The enterprises of the construction industry at the present time still do not meet all of the demand for power engineering construction. About 2.5 percent of the prefabricated reinforced concrete and 15 percent of the metal structural components are made directly at the construction sites. This organization of their manufacture is unsuitable; the products are expensive and have poor quality. The use of production capacity and profitableness of the small enterprises are lower than for large ones (Table 6-1). This type of production requires the construction at every nuclear power plant of shops, additional housing for workers involved in this production and social-cultural-general services facilities.

The fewer products built at the construction site, the less the demand for auxiliary production facilities and housing, that is, the cheaper and faster the electric power plant is built. Hence, we have an important goal: the volume of manufacture of any products at the construction site must be reduced to a minimum. This problem is solved by further development of the enterprises of the building industry. Here the optimal hauling distances from the building industry enterprises to the construction site are considered to be up to 500 km for prefabricated reinforced concrete and up to 2,000 km for metal structural components. When it is necessary to manufacture certain products at the building sites, the construction of larger workshops and enterprises as a result of combining the means for temporary structures (the heads of eight consolidated locations) of several nuclear power plants in the region, that is, construction of regional bases for a group of nuclear power plants instead of small enterprises at each nuclear power plant separately, can be economically substantiated.

Table 6-1. Level of Use of Production Capacity and Profitableness of the Prefabricated Reinforced Concrete Enterprises

| Category of Enterprises With Respect to Capacity | Use of Production Capacities, % | Profitableness, % |
|---|---|---|
| All enterprises | 90 | 17 |
| Enterprises with a capacity, $m^3$/year: | | |
| 10,000 | 78 | 5 |
| 10,000-50,000 | 84 | 15 |
| 50,000-100,000 | 92 | 10 |
| More than 100,000 | 98 | 20 |

Table 6-2. Production Areas of the Rayon Bases Reduced to 1 Million Rubles of Construction-Installation Operations

| Production Areas, $m^2$ | Enterprises of Rayon Base | | | |
|---|---|---|---|---|
| | Uncovered Storage Areas | Enclosed Warehouses | Sheds | Workshops |
| For the construction trust with annual volume of operations of 80-120 million rubles | 1,100 | 50 | 70 | 90 |
| For the heating installation trust with annual volume of operations of 20-30 million rubles* | 500 | 100 | 40 | 600 |
| For the electric wiring trust with annual volume of operations of 35-40 million rubles | 350 | 150 | 120 | 150 |

* Including masonry and heat-insulating work.

Enterprises, Structures of the Rayon Base

The rayon base has material and machinery warehouses, repair shops, subsidiary enterprises, preparation shops for preparing the intermediate products, and so on. All of the services and enterprises of the base are equipped with modern means of mechanization, transportation, accounting and control. The capacity of the rayon base and the composition of its enterprises are defined in the design. The areas of the rayon base enterprises can be approximately estimated by the data presented in Table 6-2.

It is desirable to locate the bases in the vicinity of the electric power plants under construction with mandatory observation of special sanitary norms, using the builders to create the base and the housing for the personnel. When designing the base it is necessary to try to use the relieved temporary structures of construction being completed.

The following are characteristic of the construction of nuclear power plants: the production of the reinforcing-form modules with reinforced-concrete permanent forms (see Figure 6-11); three-dimensional metal cells using lining as the form (see Figure 6-12); the reinforcing and the reinforcing-form modules with stock panel forms;

commercial reinforcing, fittings, lining billets and other metal structural components.

The basic goals of the organization of the production of the reinforcing-form modules are an improvement of their quality, maximum reduction of the expenditures of labor at the construction site when transferring their manufacture to the plant or rayon base. Beginning with these requirements, all of the operations of assembling the modules, their lining, painting, and so on are transferred to the shops of the plant or the base.

The process lines for producing modules at the present time are being improved together with the structural designs of the modules. In addition to the modules, the bases are producing bunched continuously wound stressed reinforcing for the cylindrical protective envelope of the reactor, and so on.

Temporary Structures of the Construction Bases*

The design of construction bases for each specific nuclear power plant must be carried out considering the use of the rayon base and the relieved temporary structures of the construction projects being completed.

The dimensions and the cost of the construction base for a nuclear power plant are determined by the following factors in addition to the development of the base for the construction-installation subdivisions:

the design level;

the level of organization of construction and, in particular, the outfitting with structural components and materials;

the level of specialization and the capacity of the subdivisions participating in the construction;

the level of makeup of the process equipment, the delivery times for it, the degree of modularization and factory completion, and the quality of the equipment;

the structural designs of the temporary buildings;

the nature of the basic machinery for the mass loading-unloading and assembly operations;

the type of intrasite transportation.

The influence of these factors on the dimensions of the construction base arises from the following:

---

* In contrast to the term rayon base, below the group of temporary structures of a nuclear power plant under construction will be called the construction base or construction yard.

when designing the construction base, the possibility of using permanent structures for the construction needs is defined, the blocking of the temporary structures, planning of the construction base are carried out beginning with minimum extent of the roads and service lines and minimum number of storage facilities, offices and other temporary structures. All of this reduces the expenditures on the temporary structures;

organization of the construction determines the coordination of the times of deliveries of structural components, materials and equipment with the construction times, which influences the actual dimensions of the storage areas. The deficiencies in coordinating the indicated times lead to an increase in the storage of reserves and a corresponding increase in the area;

using specialized subdivisions lowers the volume of manufacture of stock and accessories at the construction site, inasmuch as the specialized organizations are equipped with them, and consequently, it lowers the number of workshops at the building site;

the condition of the deliveries of the process equipment directly determines the dimensions of the shops and the areas for premanufacture and consolidation of the equipment into installation modules and the dimensions of the equipment warehouses. The delivery of incomplete equipment requires additional areas for storage and manufacture of equipment;

the application of gantry cranes and railroad transportation determines the coordination of the assembly and storage areas with the railroads, the length of the railroads, the motor vehicle roads and service lines;

the structural design of the temporary structures determines their costs and the possibility of repeated use at other sites.

In different phases of construction, the designs of the temporary structures have been varied in accordance with the level of development of the construction industry. At the present time the production of stock and collapsible buildings has been organized:

buildings of the container type made of wood with a metal frame, entirely of wood, from three-layer panels based on steel sheet section;

collapsible buildings made of three-layer panels, frameless and framed, folding type designed by the Orgenergostroy Institute;

collapsible buildings of the frame, folding type with the application of multilayer panels ("sandwich" type) with insulation made of polyurethane designed by the "Energotekhprom" enterprise;

air-supported structures with cold- or warm-air inflation at excess pressure and also using supporting frames without inflation.

At the present time the introduction of reinforced-concrete temporary structures in the form of shells in a pneumatic form has been cited. The shell is created by spraying the concrete on the inflated structure as a form which is removed after the shell concrete has set. In Table 6-3, the technical-economic indices of various structural designs of collapsible temporary structures are presented. The application of collapsible buildings is economically expedient in cases where they are used several times (they are circulated) at various construction sites.

The cost of the construction base and also the construction times, especially during the first period, are determined to a great extent by the concrete mix facilities. The concrete facilities are frequently made up and built in 1-1.5 years. The actual expenditures on creating them are very large. In order that the concrete facilities be put into operation in a few days and large ones, a few weeks after delivery to the site, the standardized concrete facilities have been created for power engineering construction with an output capacity of 15, 24 and 60 $m^3$/hr of concrete. Automated container-type concrete plants with a capacity of 24 and 60 $m^3$/hr of concrete, cement storage facilities and container-type mortar units have been developed. The technical-economic indices of the concrete mixers are presented in Table 6-4.

Figure 6-1 shows versions of the layout of the concrete mix facilities for building nuclear power plants with a capacity of 4-5 million kilowatts. The BSU-60 concrete mixer with an annual capacity to 190,000 $m^3$ (60 $m^3$/hr) is designed for making eight types of concrete.

Table 6-3. Technical-Economic Indices (for 1 $m^2$ of useful area) of the Collapsible Buildings 12 x 60 Meters in plar view (aboveground section)

| | | | Orgenergostroy Design | | | |
|---|---|---|---|---|---|---|
| | | | Kuybyshev Branch | | Novosibirsk Branch | |
| Structural Elements | UTS Series 420-06 | Energotekhprom Institute Design | Two-Panel | Four-Panel | Version 1 | Version 2 |
| Frame | Steel | Steel | Steel | | | |
| Enclosures | Prefabricated reinforced concrete | Three-layer with lining of sheet steel section and thermal insulation made of foam polyurethane or foam polystyrene | Three-layer with lining made of steel sheet section and DVP and the thermal insulation made of FRP | | | Wood with thermal insulation made of FRP |
| Consumption of materials: | | | | | | |
| Steel (without the mounted equipment), kg | 54.09 | 91.50 | 56.00 | 75.90 | 67.36 | 36.26 |

Table 6-3 (continued)

| Structural Elements | UTS Series 420-06 | Energotekhprom Institute Design | Orgenergostroy Design: Kuybyshev Branch: Two-Panel | Kuybyshev Branch: Four-Panel | Novosibirsk Branch: Version 1 | Novosibirsk Branch: Version 2 |
|---|---|---|---|---|---|---|
| Prefabricated reinforced concrete, $m^3$ | 0.46 | -- | -- | -- | -- | 0.07 |
| Weight, kg | 611.00 | 95.70 | 80.00 | 99.00 | 95.40 | 118.20 |
| Labor expenditures on installation, hr/hr | 3.48 | 0.13 | 0.12 | 0.15 | 1.11 | 1.12 |
| Cost, rubles | 56.50 | 78.00 | 39.97 | 50.98 | 51.69 | 39.80 |

Table 6-4. Technical-Economic Indices of the Concrete Mixers

| Indices | 409-28-30 | BSU-24 | Standardized 409-28-23 Section | BSU-60 |
|---|---|---|---|---|
| Output capacity: | | | | |
| $m^3$/hr | 30.00 | 24.00 | 48.00 | 60 |
| Thousands $m^3$/year | 94.85 | 95.00 | 151.90 | 190 |
| Weight of metal structural elements, tons | 79.80 | 54.00 | 163.00 | 69 |
| Expenditures of labor on erection, man-days | 1,296.00 | 125.00 | 3,729.00 | 560 |
| Cost, thousands of rubles | 151.20 | 95.00 | 184.70 | 80 |
| Manufacturer | USSR Ministry of Road Construction and Service Line Machinery | Orgenergostroy of the USSR Ministry of Power Engineering | USSR Ministry of Road Construction and Service Line Machinery | Orgenergostroy of the USSR Ministry of Power Engineering |

The capacity of the filler storage areas when delivering by motor transportation is designed reckoning 5-7 days of reserve and when delivering by rail, 10-day reserve of gravel and 3-4-month reserve of sand for the winter period. The capacity of the cement warehouses is taken at about 4,000 tons. For building the nuclear power plants, especially heavy concrete is required with a specific weight of 2.9-4.2 tons/$m^3$ for ore or other heavy fillers. This concrete is delivered for pouring in the structural components and usually slowly, in accordance with demand, which removes the concrete plan from the normal rhythm and delays the mass operations using ordinary concrete; therefore at the large nuclear power plants it is expedient to set up two concrete plants: one with a capacity of 60 $m^3$/hr and a second with a capacity of 24 $m^3$/hr. In practice these plants provide for the annual demand of ordinary concrete (more than 200,000 $m^3$) and they provide completely for the demand for especially heavy concrete (to 3,000 $m^3$ for one power unit of a nuclear power plant with RBMK-1000 reactor). As a result of the shortage of such plants, the nonmodular plants are being built with two and four concrete mixers with a capacity to 1,200 liters each.

The minimum composition of the construction base is as follows: storage area for the building materials and structural components with sites for consolidation of the structural components; equipment warehouses; concrete mix facilities; roads; railroads; mechanization bases; chief mechanics and power engineer workshops; general services facilities; dining rooms; heat installation organizations; electric wiring organization; the organization providing heat insulation and chemical protection; the specialized subcontract construction organizations; boiler rooms with heating networks, water supply, temporary electric power supply, air supply, gas supply.

A detailed list of the temporary structures is defined by the table approved for various types of nuclear power plants. As the plants and the rayon bases are developed, the dimensions of some of these facilities will be reduced.

In the construction of nuclear power plants, provision can be made for additional transshipment bases and other facilities and structures not entering into the presented minimum list. The shops of future rayon bases, the reinforced-concrete products construction sites, the woodworking shops, asphalt plant, bitumen facility, motor vehicle facility, remote boilers, housing bases, bases for remote hydroengineering construction projects, and so on can be among such auxiliary facilities.

The construction base must be laid out with observation of the basic requirements on the creation of an efficient construction master plan:

uncovered storage and assembly areas and also temporary structures must be sited considering reduction of the length of roads and railroads and also all the service lines;

all of the temporary structures must be placed within the boundaries of one construction base, not cutting it up territorially. The base must be located beyond the boundaries of the site set aside for expansion of the nuclear power plant;

the subsidiary production facilities which subsequently can be released to an independent industrial budget are expediently placed in one area, beginning with combination of servicing, security, common power supplies, service lines, and so on. This pertains to the concrete mix facility, the reinforced-concrete products on-site yard, the sawmill and carpentry works, the reinforcing works, including the manufacture of the reinforcing-form modules, the production of metal structural components, asphalt-concrete units, and so on;

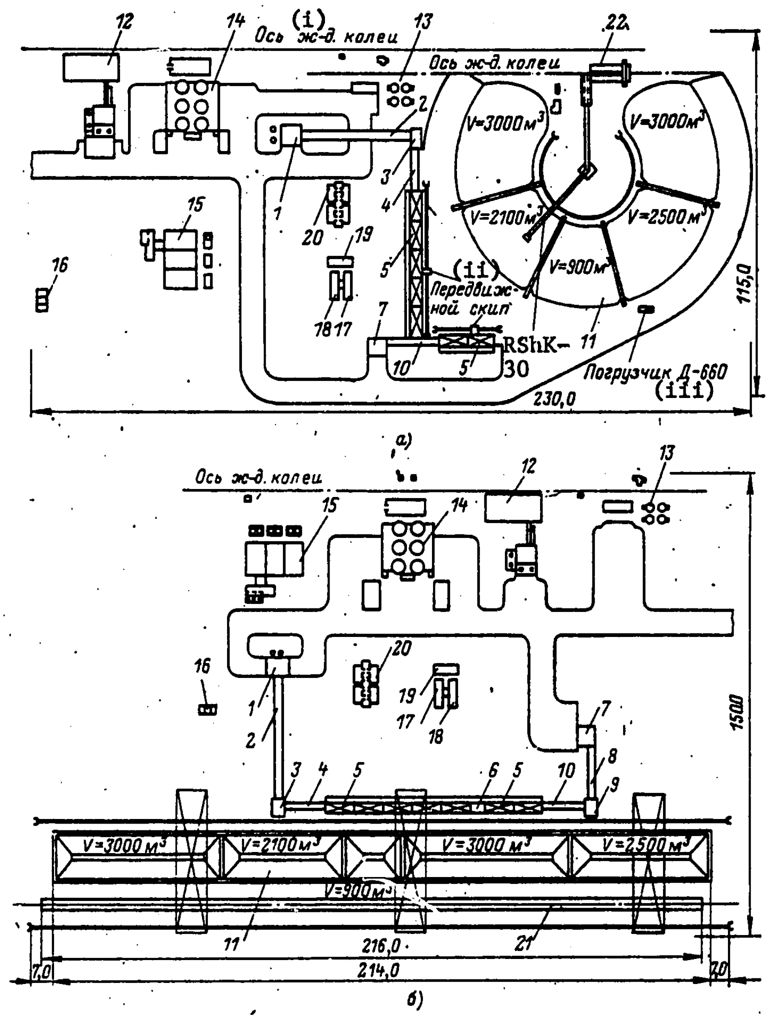


Figure 6-1. Concrete mix facility with a capacity to 120,000 $m^3$ of concrete and to 20,000 $m^3$ of mortar per year. a--version 1; b--version 2; 1--BSU-60 concrete mixer; 2--inclined gallery; 3--recharging unit No 1; 4--connecting gallery; 5--bins for heating the fillers 14 x 21 = 294 $m^2$; 6--stressing station facility; 7--RSU-20 mortar mixer; 8--inclined gallery; 9--recharging unit No 2; 10--connecting gallery; 11--filler storage with a capacity of 12,000 $m^3$; 12--lime-slaking division with a capacity of 40 $m^3$/hr; 13--division for preparation of liquid additives for concrete; 14--4,000-ton cement storage; 15--compressor station with a capacity of 120 $m^3$/min; 16--cooling tower; 17--office; 18--heating facility; 19--tool room; 20--construction laboratory; 21--unloading trestle; 22--receiver for one railroad car; i--axis of the railroad track; ii--portable charging ladle; iii--D-660 loader.

for the construction needs it is necessary to use permanent roads and railroads, warehouses, substations, boiler rooms, water lines, sewage networks, district heating, the electrical networks, and so on;

the location of the construction base, roads and railroads must provide for access and servicing of the construction site independently of operations;

all of the modern buildings must be stock or collapsible. Part of the buildings designed subsequently for use as a permanent rayon base can be built by designs for permanent structures after the corresponding technical-economic substantiations;

the territory of the construction base and all of the roads must be provided with a reliable sewer system for storm and flood water;

the organization of a transshipment base remote from the main construction base is permitted only with the corresponding substantiation. The temporary structures of the transshipment base can only be stock, for the construction of which the minimum expenditures of means are required;

the construction master plan must provide for flow construction and installation conditions at the nuclear power plants with minimum expenditures of labor and cost of construction-installation operations.

When developing the construction master plans it is necessary to be guided by the SNiP II-A.5-70 and SNiP II-M.1-71. For various stages of the construction complexes it is necessary to develop fragments of the construction master plan, for example, for the zero cycle operations, the assembly operations, and so on. The layout of the construction bases of some of the nuclear power plants is presented in appendices 6-1 to 6-3.

Mechanization and Transportation

In the construction of nuclear power plants, public transportation and construction machinery are used, that is, motor vehicle and railroad transportation. Few specific machines have been built for nuclear power plants, and this has a negative effect on the performance of the operations. For operations on the main facility and the auxiliary shops at the present time the cranes presented in Table 6-5 are used. For the storage areas and consolidation areas, traveling cranes are used (Table 6-6). The broad application of the reinforcing-frame modules weighing up to 15 tons has required the development of boom cranes with high-speed lift (to 40 m/sec). For the concrete operations at the nuclear power plants, foreign concrete pumps are used with concrete-bucket manipulators (Table 6-7) and concrete carriers with batched unloading and stimulators.

The erection of the VVER-1000 reactor envelope required the development of 1,000-ton jacks, machinery to wind the reinforcing strands and other machinery.

Table 6-5. Cranes Used for the Construction of Nuclear Power Plant Building

| Indices | Tower Cranes | | | | Caterpillar Cranes | | | | Pneumatic-Tired Cranes | | Truck Cranes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BK-1000A | BK-1425 | KB-160.2 | KB-573 (attach.) | DEK-251 | DEK-50 (DEK-631) | MKG-100m | SKG-1000 EM | KS-4361 | KS-5363 | KS-3562A | KS-4561 |
| (1) Максимальная грузоподъемность, т: | | | | | | | | | | | | |
| (2) основного подъема | 50 | 75 | 8 | 10 | 25 | 50 | 100 | 100 | 16 | 25 | 10 | 16 |
| (3) вспомогательного подъема | 10 | 5 | — | — | — | — | 20 | 18 | — | — | — | — |
| (4) Вылет стрелы основного подъема, м | 53 | 50 | 25 | 40 | 20 | 28 | 31,7 | 59,8 | 10 | 13,8 | 10 | 10 |
| (5) Высота подъема при наименьшем вылете, м | 88,5 | 96 | 6,6 | 150 | 35 | 49,9 | 80 | 101,1 | 25,5 | 14 | 10 | 10,5 |
| (6) Скорость подъема груза, м/мин: | | | | | | | | | | | | |
| (2) основного подъема | 10,7 | 6,4 | 22 | 40 | 20 | 17,3 | 3 | 4,44 | 10 | 9 | 10 | 8 |
| (3) вспомогательного подъема | 23,25 | 55 | — | — | — | — | 15 | 18 | — | — | — | — |
| (7) Скорость вращения крана, об/мин | 0,22 | 0,19 | 0,6 | 0,6 | 1,0 | 0,3 | 0,34 | 0,22 | 2,8 | 1,2 | 1,6 | 1,0 |
| (8) Скорость передвижения, м/мин | 10,83 | 12,2 | 18,0 | 0,58 | 0,28 | 0,07 | 0,08 | 0,07 | 250 | 350 | 1283 | 833 |
| (9) База (колея), м | 11,540 | 10,0 | 6,0 | — | 4,09 | 5,00 | 7,88 | 9,80 | 4,12 | 4,95 | 3,85 | 5,75 |
| (10) Общая масса крана, т | 305 | 406 | 78 | 102,7 | 36,2 | 97,25 | 196,4 | 282,7 | 25 | 33 | 14,3 | 26,1 |

Key:
1. Maximum lift capacity, tons
2. Basic lift
3. Auxiliary lift
4. Basic lift boom span, m
5. Lift height for the least span, m
6. Load-lifting speed, m/min
7. Speed of rotation of the crane, rpm
8. Speed of movement, m/min
9. Base (gauge), m
10. Total weight of the crane, tons

Preparation of Production

The engineering preparation of construction is the most important element, on which, in turn, the successful course of construction depends. Engineering preparation must be carried out on all levels of management and by many organizations of the power engineering construction system. The investigation of the preparation of construction of nuclear power plants in isolation would be erroneous, for many machines, attachments, production processes, structural components, methods of construction, and so on are being developed for construction as a whole, and they can also be used for nuclear power plants. In the sphere of direct construction of nuclear power plants, the engineering preparation for the operations must be dealt with by the managers, beginning with the foreman up.

Table 6-6. Traveling Cranes for Warehouses and Equipment Assembly Areas of Nuclear Power Plants

| Indices | KS-50-32 | KSK-30-42A | KS-30-32 | KS-30-32B | K2K-20 |
|---|---|---|---|---|---|
| Capacity, tons: | | | | | |
| Main lift | 50 | 30.00 | 30 | 30.0 | 20.0 |
| Auxiliary lift | 10 | -- | 10 | -- | -- |
| Span, m | From 42 to 20 | 42, 36 and 24 | 32 and 20 | 32.0 | 20.0 |
| Cantilever span | 15.3 and 14.3 | -- | 9.5 and 10.6 | -- | -- |
| Lift height, m: | | | | | |
| Main | 14.5 and 10.5 | 18 and 14 | 14.5 and 10.5 | 10.5 | 10.0 |
| Auxiliary | 16.7 and 12.7 | -- | 14 and 10 | -- | -- |
| Load-lifting speed, m/min: | | | | | |
| Main lift | 3.2 and 7.8 | 1.45 | 2.7 and 6.5 | 5.8 | 8.9 |
| Auxiliary lift | 8 | 7.10 | 8 | -- | -- |
| Speed of movement, m/min | 40 | 35.00 | 37 | 40.0 | 24.0 |

Table 6-7. Concrete Pumps of the Schwing Company (FRG) and the Wartington Company (Italy)

| Indices | Schwing AVR-30 | Schwing AVR-50 | Wartington-74 |
|---|---|---|---|
| Output capacity, $m^3$/hr | 30.00 | 50.00 | 46.00 |
| Maximum range of delivery of the mix, m | 300.00 | 300.00 | 400.00 |
| Maximum height of delivery of the mix, m | 80.00 | 80.00 | 80.00 |
| Maximum boom span of the concrete bucket manipulator, m | 18.50 | 18.50 | 22.50 |
| Maximum height of delivery of the mix using the boom of the concrete chute manipulator, m | 21.00 | 21.00 | 26.00 |
| Angle of rotation of the manipulator boom, deg | 360.00 | 360.00 | 360.00 |
| Overall dimensions in the transport position, m: | | | |
| Length | 7.60 | 7.60 | 10.78 |
| Width | 2.30 | 2.30 | 2.50 |
| Height | 3.35 | 3.35 | 4.05 |

The basic problems of engineering preparation are as follows:

production planning;

provision with technical forms and reports;

provision with material resources, structural components, accessories, tools and means of mechanization and transportation;

preparation of the construction site (removal of structures, drainage of the territory, building of roads, and so on);

provision with temporary structures and production facilities;

provision with power resources;

provision with personnel;

provision with construction monitoring and control means;

provision with quality control means.

Planning

The construction of nuclear power plants is realized on the basis of 5-year plans approved by the directive agencies. The annual plans more precisely define the volumes of capital investments and the construction-installation operations, the times for putting the nuclear power plants into operation considering the needs of the power engineering systems, the possibilities for construction, the readiness of the technical reports and forms, the deliveries of the process equipment. The plans must be compiled on the basis of the norms for the duration of construction, advanced methods of operations and the achievements of the advanced construction sites. All of the divisions of the plan are balanced. As a result, the design organizations, the supply plants, the makeup and supply agencies, clients and construction-installation organizations receive their parts of the plan.

Directly at the construction site in accordance with the capital investments plan and the construction-installation operations plan itemized lists of industrial, housing and social-general services construction are developed annually in which the volumes of construction, the amounts of financing by areas and the times for putting the projects into operation are indicated.

The contract organizations receive their construction-installation operations plans for the year with subsequent correction by quarters from the superior organizations. The plans are detailed by sections considering the itemized list and the plans for performance of operations, and they are the basis for the entire organization of operations.

Technical Reports and Forms

The basic technical reports and forms coming to the construction site are developed by the design organizations and the supplier plants. The construction administration during the process of the operations creates and accumulates its own technical forms and reports--logs of operations, the hidden operations documents, formulas, certificates, certificates for materials, test documents and laboratory data, working drawings, operations performance plans, and so on, part of which are classified and are appended to the acceptance documents for putting the projects into operation.



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The design organizations develop the technical-economic substantiation for the construction project, the contract design, the summary estimate, the project estimates, the detailed drawings, and so on. In addition to the detailed drawings, the design organizations compile lists of physical volumes of operations, the order specifications, diagrams and so on for accounting and ordering of material resources and structural components.

Special attention is given to substantiation of the requirement for pipe, rails, rolled metal products, cement and other short materials. The specifications and the technical specifications for the delivery of the process equipment and cables constitute a separate section of the design.

The organizing documents for the preparation of production are the designs for organization of construction and the operations performance plans and the basic construction designs. The contract design of a nuclear power plant includes the construction organization plan (POS), which, according to the Instructions for the Development of Plans for the Organization of Construction and Operations Performance Plans SN 47-74 includes the following: the calendar construction schedule, the construction master plan, the flowcharts for erection of the buildings, the instructions with respect to layout, accuracy, methods and procedure for construction of the geodetic breakdown base, the list of volumes of operations, the charts of the demand for structural components, construction machinery and transport means, calculation of the need for personnel, housing, cultural and general services enterprises, power resources, temporary structures, recommendations with respect to the administrative structure and the composition of the executive organizations with respect to the creation of safe and normal sanitary engineering conditions. For especially complicated projects, a complex, consolidated PERT chart is developed.

The POS is the basis for compiling the estimates, and it is approved as part of the contract design. The POS must be considered an important document in the preparation of production. It is necessary to be constantly guided by it considering the specific conditions of construction.

In addition to the POS, in the construction administration and the specialized subdivisions, as a result of overhead the operations performance designs are developed (PPR). In the required cases for development of the PPR by contract it is possible to use the corresponding institutes and organizations. The PPR for the most complicated unique projects and types of operations are executed at the expense of the means provided for in the summary estimate for construction of the nuclear power plant.

The PPR are used as the working document, the guide for the organization and performance of operations and also for operative planning and control of the construction process. The PPR include the following: a complex PERT chart with determination of the demand for resources and equipment, the construction master plan, the schedules for arrival of structural components, materials and equipment with the makeup lists appended, the need for personnel, the basic construction machinery, the flowcharts for complex operations, the schematics for the placement of signs for geodetic work, the decisions with respect to the protection of labor and safety engineering, the reports and forms for quality control, the measures with respect to the organization of operations by the brigade cost-accounting method, substantiation of winter operations, the calculations of the demand for power resources, the list of temporary buildings, measures to protect operating service lines. The basic technical-economic indices characterizing the solutions adopted in the design are presented in the PPR. The estimation of the cost benefit of the design solutions of the POS and the PPR is made in accordance with the SN 47-74.

The approved PPR is issued 2 months before the beginning of operations. The POS and the PPR are constantly corrected; with respect to individual sections they are newly developed, and together with the detailed drawings provide the basis for the following: substantiation of the intrasite itemized lists, the development of annual, quarterly, monthly and other plans by subdivisions of the construction site; the development of requests for all the material resources; the development of lists for makeup of the structural components, materials, and equipment; the engineering preparation of the construction projects; coordination of the operations of all of the construction subdivisions; operative management and control of the course of the operations; for other operations required during construction.

Makeup of Material Resources

In contrast to the mass power engineering projects, for the construction of which the resources are allocated by the average norms per million rubles of volume of construction-installation operations, for the construction of nuclear power plants the material resources are allocated by the actual requirement established by the detailed drawings. This system is called allocation by the physical volumes of operations. With time, when repeated types of nuclear power plants are defined, the conversion of these construction projects also to provision by norms per million rubles of construction-installation operations or other more advanced norms is not excluded. For the estimate calculations and for the design of the storage facility it is possible to adopt an approximate requirement per million rubles of construction-installation operations of nuclear power plants for metal rolled products 1,057,000 tons, cement 1,975,000 tons.

The material and technical supply of the construction-installation operations is the most important and one of the difficult problems in the organization of the construction of nuclear power plants. The system for making out the scheduling orders, sale, storage and makeup of the material resources requires an engineering base and the required technical means. Accordingly, new advanced forms of supply, makeup and partial preparation of intermediate products have appeared. The UPTK (production engineering makeup control) system has been introduced, the goal of which is provision of the construction-installation operations with all necessary materials, billets, structural components, and so on strictly by the construction schedules.

Makeup of the Structural Components

Prefabricated reinforced concrete, metal structural components and other structural elements are made at the enterprises of the building industry to which the corresponding construction administrative agencies transfer the cement and metal required for this and also at the rayon bases and in the workshops of the construction organizations. The number of types and sizes of structural components for nuclear power plants is still very large. At the first nuclear power plant it reached up to 2,000 annually for one electric power plant. This greatly complicates the production of the structural components and complicates their makeup. One of the important goals of improving the designs of nuclear power plants is standardization of the structural components. The schedules for the manufacture and delivery of the structural components must be matched with the construction schedules, and the schedules must be coordinated on the basis of the PPR.

Incomplete delivery leads to the accumulation of excessive reserves of structural components at the construction sites, it complicates the financial picture, and it disrupts the construction schedule. The system for delivery of structural components in sets justifies itself. Work is being done on improvement of this system.

Makeup of Construction Materials and Repairs

Provision with the required machinery offers the possibility of the performance of large physical volumes of work when building nuclear power plants. The demand for machinery is determined reckoning per million rubles of construction-installation operations by the procedure of USSR Gosstroy.*

The annual demand is not fully met; therefore it is very important to maintain the existing fleet of machines in a good state of repair. First of all it is necessary to introduce advanced forms of technical servicing and minor repairs. The centralized technical maintenance service provides technical servicing of the machines at the locations where they are working by means of specialized brigades with a mobile workshop. The most advanced method of repair is the unit-subassembly method. One version of it is the method of periodic replacement of repairable sets (PZRK) used in power engineering construction. It is necessary simultaneously to improve the use of the machinery. The operation of the machinery is organized by two-three-shift schedules. Special attention must be given to the preparation of the work front of the large machines and reduction of the intrashift idle time.

Training of Personnel

For the construction of nuclear power plants, just as for all power engineering construction, 30,000-35,000 young workers are trained annually at the professional-technical schools. The network of schools is being constantly expanded. A network of training stations is being widely developed directly at the construction sites where up to 80,000 workers are trained annually, and 140,000 people receive advanced training. For the construction of nuclear power plants where the performance of operations by complexes is the most effective, the organization of systematic training of the workers in several adjacent occupations is very important for the mass occupations brigades (concrete and finishing work). The brigade having workers that have skills in reinforcing work, welding, metal cutting, experience in the simplest electric wiring work in addition to the specialty of concrete workers will achieve high labor productivity indices because the hidden idle time which amounts to about 8-10 percent of the work time and the intrashift reported

* Shafranskiy, V. N., "Opredeleniye potrebnosti v stroitel'nykh mashinakh" [Determination of the Demand for Construction Machinery], Moscow, Stroyizdat, 1969.

idle time which accounts for about 10 percent of the work time are reduced. The productivity of labor of the complex brigades of this type is 20-30 percent higher than that of the ordinary narrowly specialized brigades.

In the system for advanced training of engineering and technical workers, the collective study of the designs, construction methods, the search for optimal solutions with respect to all the narrow problems of organization, technology and quality control of construction has great significance. Advanced training of the engineering and technical workers with respect to narrow professional problems is being organized in special courses, and the retraining of the management personnel is organized at the Advanced Training Institute.

Organization of Operations

The concentration of forces is the basic principle of organization of operations. The organization of operations is a set of measures with respect to the training, the support, coordination, monitoring and direction of the collectives providing for the continuous process of construction-installation work with high technical-economic indices in order to put the projects into operation at the established time. Here it is necessary to be constantly guided by the uniquely correct principle of organization of construction--not to permit scattering of forces, to concentrate all the construction forces on the most limited number of projects, creating a flow in them, completing them without relaxing the rates and only then, being guided by this principle, to begin the construction of subsequent projects.

The different construction phases have their own specific problems, but it is necessary to consider the concentration of the efforts on the projects which are the main ones in the given phase as the founding principle of the organization of operations.

Phases in the Construction of Nuclear Power Plants:

The first phase is before beginning construction. Organizational-technical measures are taken in preparation for operations. The administration of the nuclear power plant under construction is organized, an operative group is created which is headed by the general contractor for preparation of construction, soil is removed, the geodetic grid is plotted, and the structures are staked out, the reports and forms are prepared, including opening of the project; the subcontracting organizations and the procedures for settlement of them are determined, housing is leased, orders, contracts, and so on are prepared; the second phase is the preparatory period--off-site operations are performed with respect to the building of external roads, electric power transmission lines, service lines, the transshipment base, and so on and also the intrasite operations such as clearing trees, drainage of the area, the building of roads, and so on in the volume defined by the construction organization plan, including the construction of pioneer (initial) housing; the third phase is made up of the preparatory operations for basic construction, completion of the planning and construction of roads, the construction of temporary structures at the construction base, housing, and so on; the fourth phase is made up of the basic construction-installation operations with respect to the complex to be started up (the volume of operations, the performance of which is necessary for putting each power unit into operation); the fifth phase is made up of the final operations, including the projects not entering into the complex to be started up, preparation of the nuclear power plant for acceptance by the state committee.

The main goal of the preparatory period is preparation of the conditions for fast buildup of the rates of construction, beginning with the first year. In order to solve this problem, it is necessary in a short period of time to put the large-scale forces of the specialized construction and installation organizations into operation and build roads and railroads to the construction site and the worker settlement, the electric power transmission lines and the step-down substations directly next to the industrial site and the settlement, the pioneer settlements made up of stock houses with amenities, insulation, water lines and sewage. The construction of a permanent settlement is started in order to resettle the builders in it and, above all, the dormitories, dining rooms, stores and other cultural and general services enterprises are put into operation. Heating, sewage, water lines, electric power for the projects put into operation--all must be provided by permanent systems, concentrating efforts on the construction of permanent purification structures and sources of heat. Stock purification structures and, insofar as possible, electric boiler rooms can be used temporarily in place of them. For the performance of the operations in the preparatory period, first of all the stock warehouses, dining room, concrete mix facility are built, and the electric power and water supplies are provided.

Table 6-8. Norms for the Construction Times of Nuclear Power Plants (without considering the extrasite preparatory period)

| | Project | |
|---|---|---|
| | Nuclear Power Plant With RBMK-1000 Reactor | Nuclear Power Plant With VVER-1000 Reactor |
| Characteristics of the nuclear power plant: | | |
| Power, MW | 2,000 | 2,000 |
| Turbounit | | |
| Power, MW | 500 | 1,000 |
| Number | 4 | 2 |
| Reactor | | |
| Power, MW | 1,000 | 1,000 |
| Number | 2 | 2 |
| Construction time norms, months: | | |
| Total* | 75/60 | 72/60 |
| Including: | | |
| Preparatory period | 8 | 8 |
| Equipment transfer for installation** | 19-65 | 18-63 |
| Equipment installation time*** | 54/20-73 | 52/19-70 |
| Distribution of capital investments and cost of the construction-installation operations by calendar years of construction, % of the estimated project cost:**** | | |
| I | 3/7 | 2/4 |

Table 6-8 (continued)

| | Project: Nuclear Power Plant With RBMK-1000 Reactor | Project: Nuclear Power Plant With VVER-1000 Reactor |
|---|---|---|
| II | 10/14 | 8/14 |
| III | 20/18 | 16/22 |
| IV | 23/20 | 26/24 |
| V | 23/20 | 32/24 |
| VI | 18/16 | 16/12 |
| VII | 3/5 | -- |

* In the numerator we have the construction time before putting the electric power plant into full operation, in the denominator, before starting up the first power unit.
** Order months of the beginning and end of the transfer of the equipment for installation.
*** In the numerator is the total equipment installation time, and in the denominator, the order months of the beginning and end of installation of the equipment.
**** In the numerator is the distribution of capital investments, and in the denominator, the cost of the construction-installation operations.

As practice shows, the total construction time for electric power plants exceeds the normative most frequently as a result of the extended preparatory period and delayed construction of housing.

In the phase of preparation for basic construction the primary goal is creation of the construction base. It is important to organize the construction of the base by the flow system, completely providing for the zero cycle first, then the aboveground structures.

In the phase of performing the primary operations, the basic, most complex is the construction of the main facility. From the beginning of performance of the basic operations at the industrial site, it becomes the central object of construction.

The choice of the main objects in each phase and the sequence of construction are defined in the PPR. When erecting complex objects we are guided by the PERT chart, on the critical path of which operations determining the time the project is to be put into operation will be found. The consolidated PERT charts for building nuclear power plants with VVER-1000 and RBMK-1000 reactors are presented in appendices 6-4 and 6-5.

High-speed construction of nuclear power plants requires concentration of resources by years. In accordance with the construction time norms (Table 6-8) it is recommended that the volumes of construction and installation operations be distributed by years. The duration of the extrasite preparatory period is not stipulated by the norms for nuclear power plants, but by analogy with thermal electric power plants of the same power it is possible to take this period as equal to 12-15 months for nuclear power plants of both types.

All-around mechanization in the construction of thermal and nuclear power plants has at the present time reached a very high level, %:

| | |
|---|---|
| Earthwork | 99.2 |
| Loading and unloading operations: | |
| Fillers for the concrete | 98.9 |
| Metal, scaffolding, structural components | 99.2 |
| Pouring the concrete | 99.0 |
| Plaster work | 71.8 |
| Laying roads | 90.8 |

In spite of the high indices of all-around mechanization, about half of the workers do their work manually. In concrete work 45 percent of the workers do manual labor, in the installation of structural components, 12 percent, in earthwork 10 percent work by hand, in plaster work, 55 percent are manual laborers, in painting, 68 percent. The production in physical volumes by manual and mechanized labor per worker per year on the average when constructing nuclear power plants and thermal electric power plants is characterized by the data in Table 6-9.

As a result of mechanization, an increase in productivity of labor by 9.3 percent is planned in 1975-1980. Improvement of the level of mechanization is ensured by two paths:

improvement of the use of the fleet of construction machines and machinery, reduction of the intrashift idle time which at the present time is 23 percent of the work time by improving the organization of construction and labor and improving the operation, maintenance and repair of the machinery;

introduction of new machinery for building nuclear power plants and, above all, for transporting and pouring the concrete, finishing and loading-unloading operations.

Table 6-9. Annual Output in Physical Volumes Per Worker (1975)

| Types of Operations | Annual Output: Average | Mechanized Work | Manual Labor |
|---|---|---|---|
| Earthwork, thousands of $m^3$ | 18.900 | 20.900 | 1.000 |
| Installation of structural components, thousands of tons | 0.331 | 0.378 | 0.005 |
| Concrete, thousands of $m^3$ | 0.140 | 0.252 | 0.005 |
| Plaster, thousands of $m^2$ | 1.279 | 2.087 | 0.612 |
| Painting, thousands of $m^2$ | 3.035 | 7.548 | 0.888 |

The development of prefabricated construction and the improvement of the degree of plant completion of the products are needed for performance of the maximum possible volume of operations at the plants or bases and, as a consequence, to decrease the operations in construction. This promotes an improvement in quality and acceleration of construction, and reduction of labor expenditures. The optimal level of prefabrication is determined considering the economic indices.

The degree of prefabrication is reckoned in percentages, and it is the proportion of modules or structural components ready for installation coming to the construction site in the total volume of the structural component of the same type in a given structure.

The degree of prefabrication of the structural components of modern Soviet nuclear power plants is according to the estimate of the design institutes 36 percent for nuclear power plants with RBMK-1000 reactors and 26 percent with VVER-1000 reactors. The degree of prefabrication of the process equipment of the nuclear power plants is also low and is approximately estimated at 20 percent.

In the assembly areas at the construction sites, the structural components arriving from the plants are assembled into large modules which are installed on the site. The organization of the assembly areas and transportation of the modules are important elements of the organization of operations.

Along with improving the level of prefabrication of the structural elements at the present time a greater and greater effect is being achieved from the application of new materials and advanced structural components (in particular, made of polymers). As a result of improving the level of prefabrication, the application of efficient materials and structural components in the 1975-1980 period, an increase in the productivity of labor at the construction sites of the thermal electric power plants and nuclear power plants by 6.2 percent is planned. In order to ensure this growth, the power of the enterprises of the construction industry is constantly being built up.

Specialization is an important area of improvement of the organization of construction. Specially assigned associations and main administrations deal with the problems of building nuclear power plants and thermal electric power plants in the USSR Ministry of Power Engineering. The level of specialization with respect to types of construction operations at the nuclear power plants and thermal electric power plants is 75 percent for earthwork, 35 percent for the installation of concrete and reinforced-concrete structural components, 42 percent for the installation of metal structural components, 16 percent plastering operations and 14 percent painting. The productivity of labor in the specialized subdivisions is appreciably higher than in the general construction subdivisions (Table 6-10). According to the average data for the entire branch, the productivity of labor in the specialized organizations is 10 percent higher than in the general construction organizations.

Table 6-10. Annual Output in Physical Volumes Per Worker in the Specialized and General Construction Podrazdeleniye

| Types of Operations | Annual Output Per Worker: In Specialized Subdivisions | Annual Output Per Worker: In General Construction Subdivisions |
|---|---|---|
| Earthwork, thousands of $m^3$: | | |
| In the trusts: | | |
| Uralenergostroy | 15.600 | 4.100 |

Table 6-10 (continued)

| Types of Operations | Annual Output Per Worker: In Specialized Subdivisions | Annual Output Per Worker: In General Construction Subdivisions |
|---|---|---|
| Sevenergostroy | 22.600 | 7.000 |
| Yuzhenergostroy | 33.700 | 15.000 |
| Plastering, thousands of $m^2$, in the trust Uralenergostroy | 2.200 | 0.990 |
| Painting, thousands of $m^2$, in the trust Uralenergostroy | 3.050 | 2.050 |

The organization of specialized subdivisions is most effective for broad application of complex brigades on contract. Brigades of this type, performing the optimal set of interrelated operations by contract are materially interested in the quality and the times of their execution, economy of labor, materials and machine shifts of the machinery. The productivity of labor of them is 30-40 percent higher than the narrowly specialized brigades performing individual types of operations.

For nuclear power plants specialized subdivisions with respect to complexes of concrete and finishing operations are especially efficient.

Flow construction is at the present time the most advanced form of the organization of construction. The flow arrangement permits the most efficient use of the capacities of the construction organizations and the production enterprises, it ensures improvement of the quality indices of construction. The area of application of the flow method in nuclear power plant construction is broad: using this method it is possible to organize the performance of individual construction and installation processes and the erection of individual buildings. However, its application is the most effective in building a set of facilities at a nuclear power plant, which permits organization of the flows to build entire groups of nuclear power plants on this principle, that is, long-term flows.

The essence of the flow method consists in breaking down the entire process of erecting the facility or installing a unit into individual, technologically related phases, continuity of the transition from one production phase to another, and a common mode of constant loading of the workers and the machines.

The performance of each phase of the process is handed over to an individual brigade or team. The entire operations front is divided into several sections (swaths). The brigades or teams, retaining a constant composition, are moved along the work front, from one swath to the next. The first brigade performs the initial (first) phase with respect to the process sequence all the time, the last brigade completes the operations on each swath. Thus, the work is done simultaneously on several swaths; on each swath it is in a different degree of completion (coordinated in time and divided by swaths).

The process of erecting the facility can be divided into phases either with respect to individual forms of operations (narrow specialization) or with respect to complexes of operations. The complete breakdown of the process of erecting the building into narrowly specialized operations--carpentry, reinforcing, forms, concrete, and so on--gives rise to organizational difficulties and is connected with time losses. Usually we do not try to make a too detailed breakdown of operations, and groups of workers are assigned the performance of complex processes.

Many years of experience of the construction-installation organizations of various branches have shown that with flow organization it is necessary to ensure proper intercoordination of the operations of successive flows and, simultaneously, maximum coordination of individual construction processes and also general construction operations with the performance of special operations and the installation of the process equipment. The idea of combining operations frequently is mixed with the superposition in time and space in which the performance of certain operations interferes with others. Combination presupposes intelligent intercoordination of operations in which, coinciding in time, they are either divided up territorially or they can be conducted without losses jointly in one facility.

The flow parameters are related to each other by the following function:

$$T = T_1 + ([N/P] - 1)t_{step}, \qquad (6\text{-}1)$$

where T is the total duration of operations by the flow as a whole; $T_1$ is the total duration of performance of the flow of all operations in a section (swath, facility) by the brigades; N is the number of swaths (sections, facilities), $T_{step}$ is the flow step; P is the number of parallel flows.

If the operations are performed by one flow (P = 1), then in this case formula (6-1) assumes the form

$$T = T_1 + (N - 1)t_{step}.$$

If we consider that frequently

$$T_1 = nt_{step},$$

where n is the total number of successively performed processes in the flow or the number of brigades working successively in the flow, respectively, then

$$T = nt_{step} + (N - 1)t_{step} = (n + N - 1)t_{step}. \qquad (6\text{-}2)$$

Expression (6-2) demonstrates the dependence of the total duration of the operations on the flow step, that is, for equality of the flow step and the work rhythm of the brigades the power of the brigades has decisive influence on the operations duration. Therefore in flow construction primary attention is given to the forming and training of the brigades.

The number of successively working brigades n depends on the number of specialties which the brigade masters: the broader the complex of operations entrusted to the brigade, the fewer successively performed processes required, that is, successively operating brigades. Increasing the number of successively working brigades complicates control and leads to lengthening of the overall construction times.

The number of swaths N depends to a significant degree on the space planning and structural solutions of the erected buildings. The natural boundary of the swaths in multistory buildings is the floors. Each floor, if the work front is large, in turn, can be divided into a defined number of swaths. Increasing the number of swaths implies lengthening of the construction times.

The influence of the number of swaths and the number of successively performed processes (or successively working brigades) on the overall duration of operations along the flow can also be traced by isolation of the time required for the process and organizational breaks from the total duration $T_1$. In this case expression (6-2) assumes the form:

$$T = (n + N - 1)t_{step} + \Sigma z,$$

where $\Sigma z$ is the total required time for the process and organizational breaks.

Key to Figure 6-2:

1. Installation of the bridge crane
2. Powering up and testing the crane
3. Installation of the basic equipment of the reactor section
4. Machine run
5. Specialized service building
6. Installation of auxiliary equipment
7. Reinforcing of the cylindrical part to the 18.7-m level
8. Structural components of the reactor section to the 11.8-m level
9. Installation of pit equipment
10. Off-site preparation period
11. Intrasite preparation period
12. Structural components to the ... level
13. Cylindrical part of the envelope
14. Construction of the dome, phase ...
15. Completion of construction operations
16. Envelope cornice
17. Installation
18. Thermal insulation of circuit I
19. Adjustment No 1
20. Complex of module I
21. Hot test run, inspection, adjustment operations
22. Power unit ...
23. Startup and adjustment operations
24. Inspection of circuit I
25. Stressed reinforcing of the envelope and dome
26. Auxiliary equipment

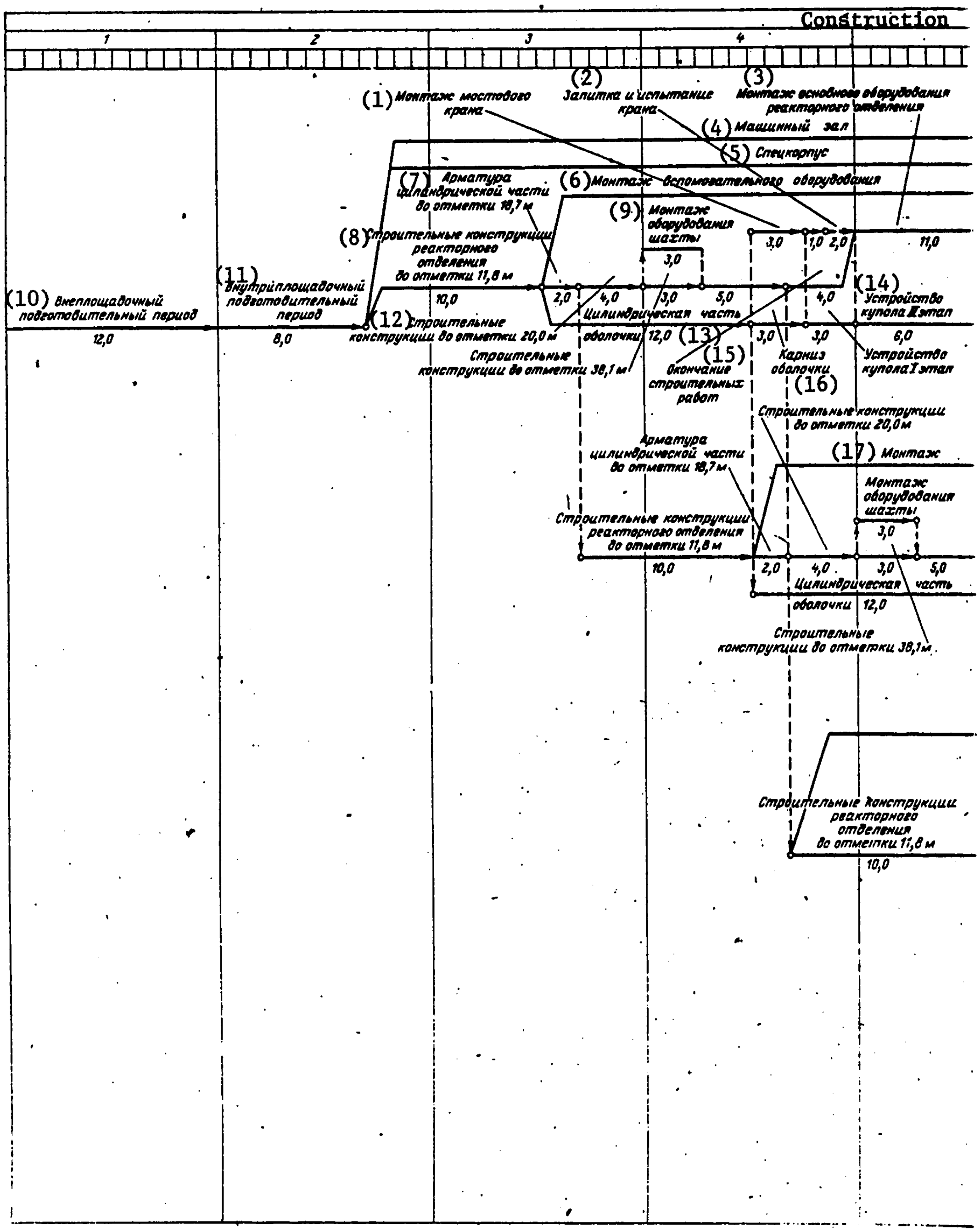
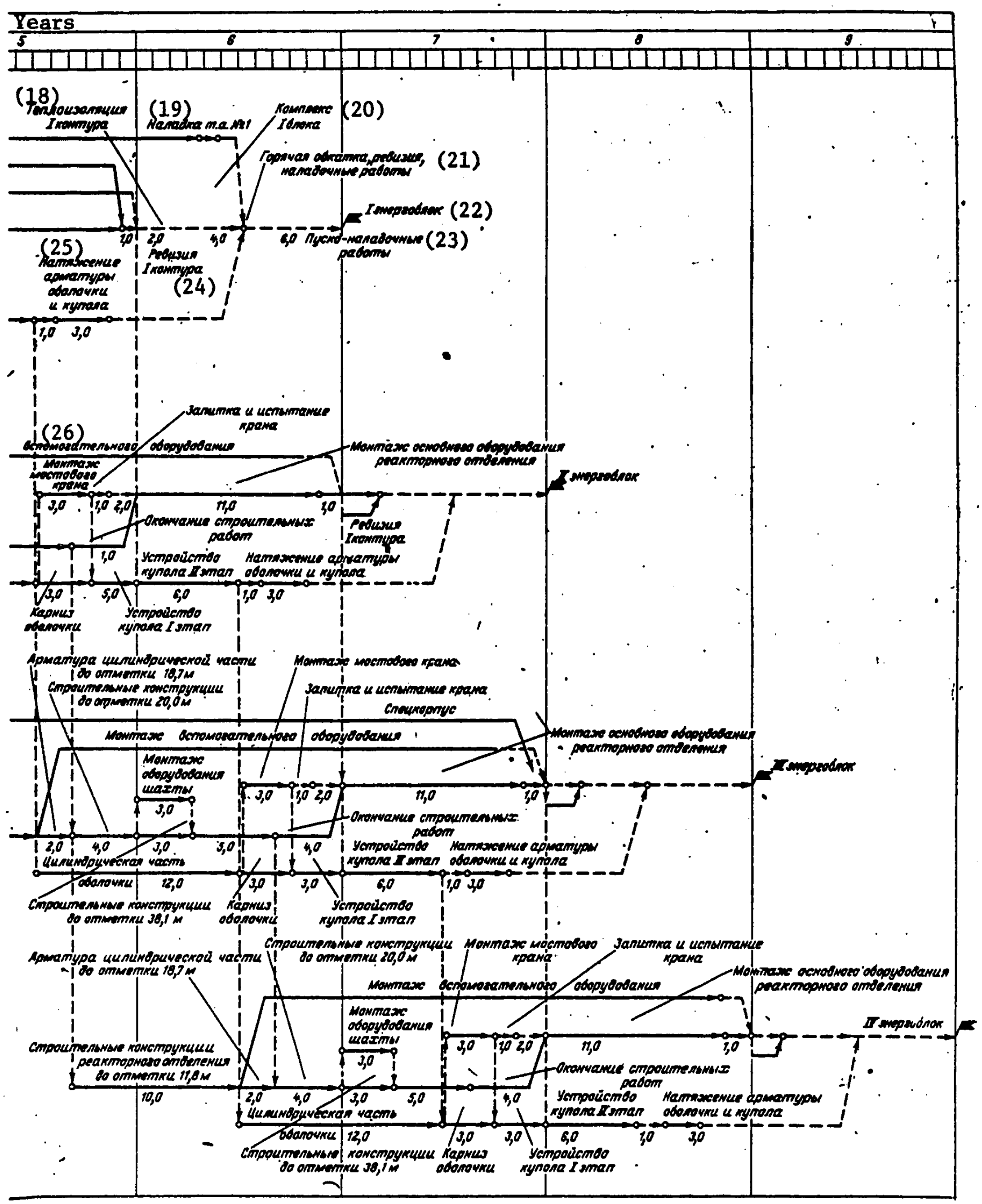



Figure 6-2. Consolidated PERT model of flow construction of the reactor sections




of nuclear power plants with four VVER-1000 reactors.

With an increase in the number of swaths and also the successively working brigades, the time losses on organizational and process breaks will increase [61]. The organization of the operations by complexes always accelerates construction, for there are fewer of the indicated losses.

When erecting the facilities by the flow method, as has been pointed out, it is necessary to organize several independent specialized flows that are coordinated with each other. Usually each specialized flow is performed by the forces of a special construction or construction-installation administration or section. The swaths in the building can be common for all specialized flows, but cases are possible where the building is broken down into a different number of swaths for each specialized flow.

Inasmuch as the organization of the flows presupposes the working of the brigades with constant composition and equipment, the flow can be created only at the building or structures with uniform structural components. If the complex includes various buildings that are different with respect to structural design, then for organization of flow construction they are grouped by the attribute of uniformity of structural components, and an independent flow is organized for the construction of each such group.

The recurrence rate of the operations for each given brigade creates the conditions of specialization, improvement of technology, growth of mastery of the workers, accumulation of experience and improvement of the accessories and tools. This is one of the most important features of flow construction ensuring technical progress, improvement of quality and improvement of the economic indices of construction.

The long-term flow is one of the methods of improving the organization of operations. The program for introducing 13-15 million kilowatts of power at the nuclear power plants in the 10th Five-Year Plan with intermediate work for significant increase in the introduction in the next 11th Five-Year Plan creates the prerequisites for organization of long-term nuclear power plant construction flows. The construction of groups of like electric power plants can be combined into flows. For each flow it is necessary to ensure the following conditions: the flow includes relatively closely located nuclear power plants; the plans for the nuclear power plants are alike; the process of erecting the plant is unified; the total volume of construction-installation operations of the flow must correspond to the capacity of one general contracting construction administration (trust); the operations are performed by the subdivisions specialized in the complexes of operations; provision of the construction sites with structural components is realized from the enterprises of the construction industry and the rayon bases; the UPTK system is organized; the coordinating control center for all flows is created; operative-dispatch centers are created in each general contracting construction administration (trust).

The groups of nuclear power plants making up the construction flows can be planned on the basis of the overall schedule for introduction of nuclear power plants in the distant future (for 15 years), which will be developed beginning with the demands of the power system and expected delivery of basic process equipment. The types of nuclear power plants and the regions of their construction which are considered when compiling the flows are reflected in this chart.

Inasmuch as the reactor section has the most complicated structure determining the construction time, the flowchart is developed for it. An example consolidated PERT model of flow construction of the reactor sections of four power units with VVER-1000 is presented in Figure 6-2. PERT models are developed also for the remaining projects. The primary construction flows by parts, structures, as is obvious from the presented PERT model, are formed from the conditions of uniform loading of the subdivisions over the construction time of all four power units, rhythmic introduction of capacity with a step size of 12 months and observation of the construction time norms by periods (Table 6-11). The base of the flow in the given case is the primary subdivision specialized with respect to complexes of concrete operations--four partial flows of the reactor sections and a fifth partial flow of the specialized service building. In building the same structures within the boundaries defined by the PERT model the subdivisions encompassing each special flow having its own means of mechanization and equipment can be sections administratively. The annual volume of operations of the five sections (five partial flows), as the calculations show, is about 12 million rubles, which is sufficient for one construction-installation administration specialized in performing the set of concrete operations of the special structures of the nuclear power plant.

Table 6-11. Duration of Construction of One Power Unit of the Nuclear Power Plant, Month

| Indices | VVER-1000 | RBMK-1000 |
|---|---|---|
| Total duration of construction considering the off-site preparation period: | 72 | 72 |
| Including: | | |
| Off-site preparation period* | 12 | 12 |
| From the beginning of intrasite preparation period to the introduction of the first power unit | 60 | 60 |
| Of them: | | |
| Duration of the intrasite preparation period | 8 | 8 |
| Power unit introduction step | 12 | 15 |

* The duration of the off-site preparation period of 12 months is taken by analogy with the construction of 1,800-MW thermal electric power plants.

Table 6-12. Approximate Specific Physical Volumes Per Million Rubles of Cost of Construction and Installation Operations

| Types of Operations | VVER-1000 | RBMK-1000 |
|---|---|---|
| Monolithic concrete and reinforced concrete, thousands of $m^3$ | 1.65 | 1.80 |
| Prefabricated reinforced concrete, thousands of $m^3$ | 0.44 | 1.23 |
| Reinforcing with fittings, thousands of tons | 0.20 | 0.24 |
| Steel structural components, thousands of tons | 0.11 | 0.17 |

Note: For calculations of the volumes of operations of nuclear power plants under construction it is necessary to use the design data.

| Designation | Проектная мощность, МВт (1) | Стоимость СМР, млн. руб. (2) |
|---|---|---|
| Nuclear power plant No 1 | 6000 | 67,2 |
| Итого строительные работы, млн.руб. | | (6) |
| Nuclear power plant No 2 | 6000 | 67,2 |
| Итого строительные работы, млн.руб. | | |
| Итого строительные работы по потоку (7) | млн.руб. | (8) |

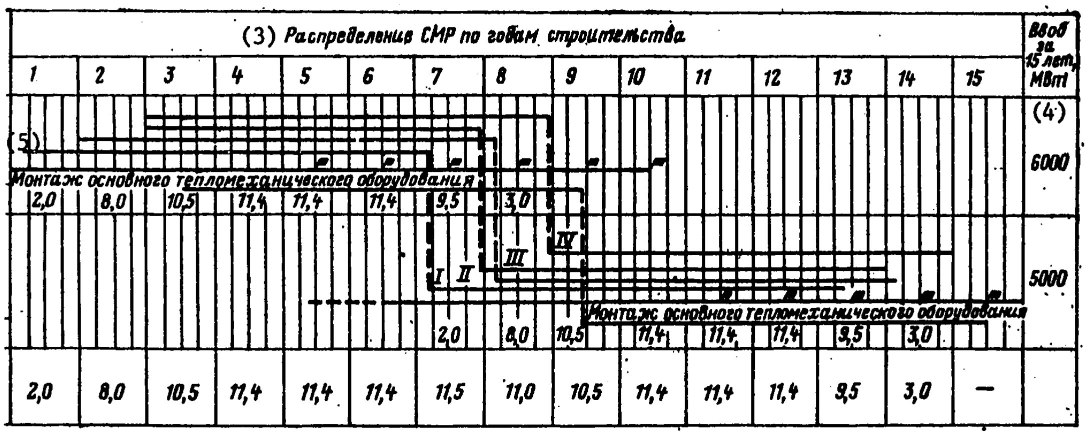



Figure 6-3. Chart of specialized construction flows of the reactor sections of a group of nuclear power plants with VVER-1000 reactors.

Key:
1. Design capacity, MW
2. Cost of construction and installation operations, millions of rubles
3. Distribution of construction and installation operations by years of construction
4. Introduction after 15 years, MW
5. Installation of the basic thermomechanical equipment
6. Total construction operations, millions of rubles
7. Total construction operations by the flow
8. Millions of rubles

The construction of the reactor sections of a group of nuclear power plants can be combined into one flow (Figure 6-3). Analogous developments are made for all of the nuclear power plant facilities. For creation of a summary construction schedule for an individual nuclear power plant based on the PERT models of the reactor sections and other facilities and also the summary estimate, the cost of the construction-installation operations is distributed with respect to basic types of operations--construction, heat installation and electric wiring, and the number of workers is reckoned by years based on the volumes of the corresponding operations and the planned annual output per worker. The results of the calculation are presented in the chart.

Approximate data on the specific volumes of construction and installation operations per million rubles of estimated cost presented in Table 6-17 can be used for course design.

The summary chart of the flow construction of a group of nuclear power plants is compiled on the basis of the summary charts for the construction of individual nuclear power plants. The construction flow of a group of nuclear power plants is not specialized, having no ties to the parallel flow of other groups of nuclear power plants. The flows of all groups are related to each other by the operation of the enterprises delivering the equipment, the structural components, materials and also the operation of the basic subcontracting organizations for heat installation and electric wiring, insulation, and so on. Under flow conditions each of these organizations works by its own schedule which is coordinated with the builders. The mutual correction of the flowcharts of the groups of nuclear power plants offers the possibility of obtaining a summary chart of rhythmic introduction of capacity with respect to the entire ministry with maximum approach to the requirements of the power systems. The data from the summary chart can be used when developing plans for capital investments, deliveries of equipment, resources and the organization of construction.

Operative Methods of Organizing Construction Production

The basic goal of operative administration is ensurance of rhythmic operation of all the construction subdivisions so that each will fulfill the planned indices and will deliver the operations front on schedule to the next subdivisions, ensuring that the facilities will be put into operation at the established times with high quality.

For the fulfillment of this goal the attention of the nuclear power plant construction management at all levels is concentrated on the following basic problems:

detailed development of the plans, the PPR and the charts in order to determine the assignments and also the measures with respect to ensuring completion of them for the year, quarter, month, 10-day period, week, day for each subdivision and delivery of them to the executive agents;

ensurance of the capacity of the subdivisions required by the plan. Training of personnel and manning the subdivisions with workers in the required specialties and engineering and technical workers, supplying the machinery, inventory, tools, transport means, and so on;

preparation and support of the operations front and the workplaces, constant coordination and control of the work of adjacent organizations, intensification of lagging operations in order to accelerate the preparation of the operations front, implementation of measures for engineering preparation of subsequent operations, safety engineering and industrial sanitation conditions;

support of the operations with materials, structural components, products, and so on, timely delivery of them to the central warehouses and makeup units, organization of subsidiary enterprises and facilities and bringing their capacity up to that required by the POS and the PPR calculations, organization of the centralized system of delivery of materials, structural components and products to the construction projects by hourly schedules monitored by the dispatch service;

the constant monitoring of fulfillment of the plans, meeting the schedules, the assignments by all subdivisions and taking the required measures to see that they are fulfilled, organization of a service for monitoring the fulfillment of the assignments, quality control, permanent personal control of the course of the operations, the performance of operative checks, the holding of technical and production meetings;

everyday work with the collectives, organization of socialist competition, introduction of advanced methods of organization of operations and labor, incentives for fulfillment of the plans, assignments and high quality of operations, mobilization of the collectives for fulfillment of the goals by each construction subdivision.

The basic work with respect to operative management and support of construction is performed by the engineering and technical personnel and the brigade leaders. The use of the engineering and technical personnel and brigade leaders as direct organizers, the technical leaders of construction production and educators of the collectives is a sign of proper organization of production. Such organization is achieved on strict fulfillment of functional obligations and operations deadlines by each construction subdivision.

The limits of the operations and the functional obligations of the subdivisions are defined by the structure of the construction organization. In the construction of nuclear power plants the structure varies as the volumes of operations grow, as the material base develops and the subdivisions become specialized. At the present time the administrations for the construction of large nuclear power plants have subdivisions provisionally divided into three groups:

the construction administrations or construction operations sections, the base for which is the worker collectives;

subsidiary enterprises, transport subdivisions, the chief mechanical engineers and power engineers sections, and so on with the working collectives;

functional sections--planning, production engineering, personnel, labor and wages, quality inspections, bookkeeping, equipment divisions, supply, dispatch, laboratories, and so on not having workers or with an insignificant number of workers.

The construction administration coordinates the work of the subdivisions subordinate to it and also all of the subdivisions of the subcontracting organizations.

Clear-cut delimitation of the operations, functional obligations of all of the subdivisions is a necessary condition of the successful organization of construction production. It is possible to achieve the greatest clarity of delimitation of the construction operations when the structure provides for the performance of a set of concrete and a set of finishing operations by specialized subdivisions. Thus, when building the Kola Nuclear Power Plant, all of the concrete operations were performed by an individual construction administration; when building the Kurskaya Nuclear Power Plant, the entire set of finishing operations was performed by the construction administration of finishing operations.

The operative control of construction under the operating conditions of specialized subdivisions by complexes of concrete and finishing operations is facilitated, the organization of the operations and their quality are improved along with all of the technical-economic indices. The performance of the operations by complexes creates all the conditions for flow-phase technology; the number of unfinished operations and labor expenditures are reduced.

Systematic monitoring of the fulfillment of the assignments and the charts on the part of the construction administration is achieved by the organization of operative accounting, checking at the operative meetings and personal monitoring. Operative accounting is carried out by the dispatch service or the PERT planning service. At large construction sites operative monitoring, including the monitoring of the daily assignments with respect to types of operations is carried out using a computer by the automated control system programs. The monitoring data are used at the operative meetings.

The monitoring of the course of operations at the nuclear power plants is a very complex problem. The organization of the operations by the flow-phase process charts and also the performance of them by specialized subdivisions facilitate monitoring inasmuch as the operations performed by one subdivision are coordinated and monitored by this subdivision. Here the greater the material possibilities in the given subdivision, the more operatively the production problems are solved and the more successfully the operations are performed. The brigade leader, foreman, superintendent, section chief and construction administration on their own levels monitor the course of operations with the degree of detail required for the given level. Thus, if the brigade leader is interested in the performance of assignments by a worker on time by operations, then it is sufficient for the construction administration chief to know the fulfillment of the daily or weekly chart in physical volumes of finished production (for example, cubic meters of concrete poured), the fulfillment of the chart for the acceptance of the subassemblies of the facility of an adjacent organization (for example, the number of facilities accepted for finishing), and so on.

Timely organization of operations, construction control, monitoring of the course of the operations require constant work with PERT models. In the necessary cases the PERT models are corrected, reworked, worked out in more detail by fragments in order to ensure performance of the operations in the given time.

An important role in the organization of construction production is played by the formation and the work with the complex brigades by contract agreement. A contract brigade is obligated to perform a set of operations by a specified time with defined technical-economic indices; the contract administration is obligated to support the brigade with all that is necessary and provide it with incentives. Under the conditions of nuclear power plant construction, as a result of shortages of technical documentation, makeup of products and for other reasons, difficulties arise when organizing the contract brigades. A study of the causes holding back the introduction of the system of contract agreements on a mass scale, surmounting difficulties that arise when organizing the contract brigades as a highly efficient form of attracting workers to the construction administration is an urgent problem of organizing construction production at the nuclear power plants.

In addition to the brigade contract, other methods of involving workers in the construction administration, improvement of the activity of the industrial workers and the engineering and technical workers are used. Broad participation of the collectives in socialist competition, collective agreements, production meetings, the development of efficiency expert work, the introduction of advanced methods of organization of labor, technical losses and other means of developing initiative and involving industrial workers and engineering and technical workers in public life promote improvement of the organization of construction production.

The organization of construction production, the monitoring of the operations are realized not only by the personnel directly involved in the given construction project. The construction site is accountable to superior organizations with respect to the important positions on the PERT models, the fulfillment of the plan and financial activities. The problems which cannot be solved by the forces of the construction site are transferred to the superior organizations which, supporting and coordinating the work of many construction sites, take the required measures to solve the problems arising, in necessary cases they correct the activity of the construction site, operatively ensuring the fulfillment of the government plans.

Construction Production Control System

The structural and functional interrelations of the organizations and subdivisions engaged in management, planning, support and monitoring of construction sites, including coordination of all the organizations participating in the construction and installation operations, in deliveries, distribution, makeup of material resources and manpower and process equipment, provision of technical reports and forms, financing, and so on realized by the subdivisions of the USSR Ministry of Power Engineering and also other organizations and departments are combined under the united concept of the control system.

The improvement of the control system in power engineering construction is taking place with respect to all areas of control and production. One of the important areas is improvement of the structure of control by simplifying the multistep, multilink structures. The associations organized at the present time make it possible to bring the administrative apparatus close to the construction sites. The three-link structure of control is being created: ministry--association--construction site. This is improving the operativeness of the work of the administrative agencies, and the number of people involved in the administrative apparatus is reduced. The associations have the enterprises of the construction industry, the design and, when necessary, scientific research subdivisions servicing the direct needs of the associations attached to them. Specialized construction-installation subdivisions are formed within the associations which permit the required distribution of forces of the association. This improves the independence of the associations, the possibility of solving the largest number of problems without going to the ministry. The effect of the structure of construction control in production on the quality, organization of construction production and operativeness control was demonstrated above. In the control area, directly in the associations and other subdivisions of the ministry, efficient structures are being developed, the functions are being more precisely defined and delimited in order to improve the work of the administrative apparatus and improve its operativeness and also to intensify the work on the problems on the prospects, planning and engineering policy. At the same time the improvement of the control system is leading to a reduction in the number of administrative personnel.

The improvement of the control system is aimed at improving the capital construction, in particular, the operative management of construction production. The criteria for evaluating the control system, the work of the administrative apparatus on all levels include the work of the construction sites, the fulfillment of the planned assignments by them with respect to introduction of capacity and facilities, growth of productivity of labor, improvement of quality and economic indices.

## 6-2. Special Features of Construction-Installation Operations

### Special Features of Nuclear Power Plants

The special features of nuclear power plants have significant influence on the technology and the organization of their construction. Let us consider some of these features [70].

The complexity and specific nature of the layout are determined by the placement of the equipment in reinforced concrete boxes. Access to these boxes is organized from corridors through sealed cast iron doors. The delivery of awkward or heavy equipment through the corridors is frequently difficult or impossible; therefore it is necessary to organize its delivery from the top after erecting the walls of the boxes, and only after that erecting the monolithic or prefabricated ceilings, that is, coordinated execution of the construction and installation operation is necessary and expedient, in connection with which the delivery times of the equipment must be strictly coordinated with the construction schedules.

The unique, nonrepeating nature of the volume and composition of the operations by levels of the structures is explained by the various floor plans of the building on all levels, and it requires the performance of different amounts of monolithic and prefabricated construction, reinforcing, forming and concrete work. Under these conditions it is expedient to use specialized complex subgroups to perform the entire complex of concrete operations.

The high saturation with process equipment, instruments and cable products creates difficulties in performing the operations. It is necessary that the installation of the equipment be serviced by individual machinery and rigging and in a given group of facilities that the fewest number of subgroups of workers be present simultaneously. The high saturation of the facilities with equipment requires a system for acceptance of completed work and transition from one phase to the next by the acceptance committees.

The radioactivity and structural design of the equipment require complete cleanness and dustfreeness during its installation. Exceptionally rigid requirements on cleanness are imposed when assembling the reactor core, lines and equipment of the primary circuit in connection with the fact that individual elements of the equipment, in particular, the reactor core, have small cross sections, and contamination of them can lead to serious emergencies. The cleanness promotes improved quality of the work and a reduction in the startup and acceptance times. The maintenance of cleanness in the facilities is facilitated after completion of such operations as mass installation of concrete structures, plastering, priming, spackling, the installation of temporary nondust producing floors and also inclusion of the heating and ventilation. The phase of the erection and installation work with this degree of completion of the construction is called the "clean" phase.

During installation of the reactor, the primary circuit equipment and some of the especially responsible equipment, it is necessary to organize systematic wet cleaning of the floors and the facilities and equipment with vacuum cleaners. The ventilation and heating systems must remove dust and fumes, maintain dryness of the air and a positive temperature. The entrance to the facility is through decontamination stations with mandatory changing of clothes and monitoring of tools brought into the installation zone. This phase of the erection and installation work is called "especially clean."

The increased requirements on quality of the construction-installation operations are imposed because an emergency at nuclear power plants is significantly more dangerous than at thermoelectric power plants.

The basic conditions for high-quality work are a clearcut engineering sequence and defined constant operations boundaries for each flow. Therefore the flow-phase construction and organization of technical quality control by phases are recommended.

The phasing of the process of erecting nuclear power plants is one of the basic principles of organizing nuclear power plant construction aimed at improving the quality of construction, acceleration of it, and reduction of expenditures of labor and cost.

The novelty of the construction-installation processes requires that the engineering personnel carefully study the designs of the nuclear power plants and equipment and make timely preparations for new production processes. It is necessary to improve the technical information dissemination, exchange of experience in building the nuclear power plants, and to organize the research and development of new production processes at the scientific research institutes and production subdivisions.

Thus, consideration of the influence of the specific features of nuclear power plants on the technology and organization of construction leads to the following basic conclusions:

Flow-phase construction technology is expedient, phasing of the operations must be reflected in the construction PERT charts;

The organization of the engineering monitoring and acceptance must provide for high-quality completion of the operations by phases, and this should be fixed by the corresponding forms and reports. An expedient form of quality control can be provided by the quality inspectorate, construction laboratories, geodetic services and technical erection installation control services, and the form of acceptance of completion by phases can be committees with the appropriate composition;

The construction-installation operations must be performed by specialized subgroups. The subgroups for concrete work must be created on the basis of complex brigades of concrete workers;

It is expedient to reinforce development of new production processes and also to improve the scientific and technical information dissemination in nuclear power plant construction.

Flow-Phase Technology

The special nature of the layout of a nuclear power plant, as has been pointed out, requires joint construction and installation operations. Beginning with the specific nature of the nuclear power plant layout, it is expedient to organize the flows of work being performed from bottom to top, that is, beginning with the basement facilities, all of the operations by levels of the structures are performed successively [71].

The first flow of operations includes erection of the reinforced concrete structures by the efforts of complex brigades of concrete workers. After erection of the walls of the first level, the foundations for the process equipment and removal of the forms, the operations in the second flow begin -- rigging the awkward equipment. After completion of rigging of the equipment, the second flow operations continue -- the brigade of concrete workers covers over the boxes with prefabricated or monolithic structures. It is permissible to leave openings in the covers for delivery of equipment to the installations right after completion of concrete operations only in cases provided for by the peculiarities of the rigging systems or when the equipment has not arrived on schedule. The finishing-off of the openings over the boxes, if it is not done in the general flow of concrete operations, requires additional expenditures of labor and time.

In order to facilitate removal of the forms, preparation of the surfaces for finishing (for drying out concrete, and in the winter, to eliminate ice) after the concrete work is done for covering the boxes at each level it is necessary to provide heating and ventilation.

Thus, it is possible to define the sequence of operations (in consolidated form) performed on each level:

1) Installation of the reinforcing-forming modules or cells of the walls, and at places in the forms, welding of the lining;

2) Installation of individual special fittings in the walls;

3) Pouring the walls, the foundations of the process equipment, removing the forms and cleaning up the facilities;

4) Installation of heavy and awkward equipment;

5) Installation of temporary heating and ventilation systems;

6) Assembly of the modules of the ceiling-floors or installation of the forms for the ceiling-floors, reinforcing work, completion of lining of the boxes;

7) Installation of special fittings in the ceiling-floor slabs;

8) Concrete pouring in the ceiling-floors;

9) Inclusion of heating and ventilation;

10) Preparation of the boxes for acceptance for finishing;

11) Acceptance of the boxes for finishing.

The acceptance of a group of boxes for finishing completes the first phase of construction operations which must be clearly reflected in the PERT charts as a major control event.

The next phase of construction-installation operations is preparation of the facility for "clean" and "especially clean" installation and erection work. The sequence of the operations of preparing the facilities for "clean" installation work requiring single installation of scaffolding for construction work in each box is as follows:

12) Installation of scaffolding;

13) Finishing of the holes made by the anchor fastenings of the form, floating of the joints, and so on (in the worst case, floating or plastering over the concrete);

14) Installation of permanent biting;

15) Installation of the fasteners in the walls and ceilings and also in the floors;

16) Installation of temporary explosion-proof lighting and ventilation;

17) Priming, spackling of the ceilings and floors;

18) Removal of scaffolding, the temporary explosion-proof lighting and ventilation system, and equipment packaging material;

19) Installation of tubes for cables, the fittings of the temporary and permanent drains in the floors;

20) Cleaning the boxes;

21) Waterproofing the floors;

22) Pouring the cement floors to the final levels;

23) Painting the cement floors (or laying temporary cleaning floors for other construction);

24) Acceptance of the group of boxes for "clean" installation and erection work.

It is necessary to consider some of the above-enumerated operations in more detail.

Installation of Permanent Lighting Systems. At some of the construction sites, two lighting systems were installed -- temporary and permanent -- which gave rise to an unjustified increase in expenditures on lighting. On the basis of the work experience of the Beloyarskaya and foreign nuclear power plants, it is recommended that the permanent lighting system be installed directly. Temporary light fixtures must be installed in the boxes and lower corridors. The wiring maintenance must be provided by the installation organizations taking over the facilities for installation and erection work.

Waterproofing the Floors. When performing "wet" construction operations, performing hydraulic tests on the equipment and also as a result of atmospheric precipitation during construction there are frequent water leaks through the floors and ceilings as a result of which the water gets into the boxes at lower levels, it floods the equipment and spoils the finish. In order to prevent leaks it is necessary to waterproof the floors on all levels and provide a temporary drainage system to catch the water. The waterproofing of the floors is accomplished by applying mastic based on ethynol lacquer. The composition and the process of applying the mastic on wet and dry floors were developed by the Orgenergostroy Institute. It is possible also to apply the mastic to dry floors in the winter at temperatures to -20-30°C.

Pouring the Cement Floors to the Final Marks and Painting Them. These operations are performed to obtain temporary, clean, dustfree floors during the "clean" installation period. The painting of the floors is also temporary. Part of these floors are destroyed during installation of the equipment. To protect against dust, any other procedure, for example, in individual cases, using a sheet metal flooring, can also be used. The phase of accepting the facilities for "clean" installation can be planned and formulated by the committees for all levels and groups of facilities and be reflected as a most important event in the PERT chart.

As is obvious from the list of operations performed from the beginning of the construction operations to accept the facility, the majority of them can be grouped into complexes of concrete and finishing operations, that is, instead of 24 operations there will be 10 complexes (Figure 6-4), and they can be performed by complex brigades of concrete workers and finishers.

From the time of acceptance of the level or group of facilities for "clean" installation, the basic flow of all types of installation work begins, and the installation organization which accepts the facilities becomes responsible for maintaining cleanness, maintenance of the electric wiring for lighting, and so on. Other operations in this group of facilities can be performed only by technical permission of the lighting wiring organization. It is necessary to try to see that the equipment and instruments are installed during the "clean" and "especially clean" installation phases and that the pipelines and cables are laid during these phases. Only individual instruments and types of cable, the installation of which in the phase is considered inexpedient, can be considered an exception, however, the provisions for fastening them must be made before the final finishing.

The breakdown of the facilities into groups and levels which are transferred to "clean" installations, must be made in the plan for performing installation operations and must be taken as the base when developing the PERT chart.

It is very important to achieve full completion of all installation operations before starting up the nuclear power plant in order to insure the operating reliability of the plant and also to reduce labor expenditures, for the performance of finishing work in the operating shops of the nuclear power plant or after the finishing operations have been completed causes significant increase in labor consumption. The delivery of the process equipment, instruments and cable products in the indicated installation systems strictly on schedule is a key condition of flow organization of operations.

The acceptance of the facilities for clean finishing completes the phase of installation operations (without hydraulic testing, washing and proving), which is reflected in the PERT chart. The acceptance for clean finishing is by groups of facilities or levels, and it is formalized by a document. In other facilities, in particular, those located higher up, the installation operations can be incomplete.

The breakdown of the facilities by groups transferred for "clean" finishing is defined in the PPR and the PERT charts. After transfer of a group of facilities or level to the builders for clean finishing, the period of limited entrance of the installation workers to this zone begins. During hydraulic testing, blowdown and washing the pipelines and testing machinery which can be done after the performance of the clean finishing operations, it is possible to damage part of the painted surfaces and before acceptance of the facilities for operation it is necessary to do final painting. In the instruments and norms for material consumption provision must be made for expenditures on repeated painting with one coat of about 30% of the surfaces subject to painting. The amount of damage to the finished surfaces during finish installation and prestartup operations and also the expenditures of labor on elimination of them can be reduced with proper organization of operations: completion of the installation of the equipment before the final finishing; painting of the facilities and laying of the floor made of plasticized material and completion of thermal insulation before the prestartup operations; single installation of scaffolding.

The expedient sequence of operations in the "clean" finishing phase is presented below [72]:

Removal of the temporary clean floors, repair of couplings;

Whitewashing the couplings, laying plasticized material with fitting;

Setting up scaffolding, repairing the concrete surfaces or plaster, setting up temporary explosion-proof ventilation and lighting, spackling, priming, painting the ceilings, walls and equipment;

Completion of thermal insulation operations, including lining with sheet aluminum;

Installation of permanent light fixtures;

Inspection of equipment;

Fixing damage to the paint, final painting, dismantling of the temporary ventilation and explosion-proof lighting systems, removal of scaffolding, removal of garbage and waste, washing down the plasticized material;

Acceptance of the administrative facilities.

In the clean finishing phase, the operations are performed by a complex brigade of finishers, a brigade of plasticizers and also the installation organizations. In the indicated version the laying of the plasticized material is done in advance. This is important for creating favorable conditions for inspecting the equipment and other prestartup operations. In addition, as has been pointed out, it is not necessary to shift large volumes of finishing and plasticized material operations to the very end of the schedule, for this leads to extraordinary demands on the finishers before startup, it lowers quality and can increase the overall construction time.

The inspection of equipment can be made also in a different sequence; it is important that the most labor-consuming operations of painting the facilities and equipment and also laying the plasticized material be completed before this.

The acceptance of the administrative facilities is the most important event of the PERT chart. It is normalized by a committee document which records the end of the basic construction-installation operations. From that time, the administration, being the responsible organization with respect to the group of accepted facilities, admits the builders and installation people for working on the system of allowances adopted in operation. Further startup and adjustment operations are conducted with the participation of a limited number of installation people and builders according to the schedules established by the startup committee.

Figure 6-4 gives a PERT model of the described operations. In order to provide the required technical control and the required responsibility for quality and completion of operations, intermediate acceptance of work by the committees is practiced with the participation of the technical inspectorate, the administration, the author's inspection of the design organization and other required subgroups.

A total of 14 control events were defined from the beginning of erection of a level to acceptance of the administrative facilities for operative servicing; five of them are formalized by committee documents, and nine are entered in the operations log.

The following events are formalized by documents (indicated by a "flag" in Figure 6-4): hidden operations before pouring the concrete in the walls; hidden operations before pouring the concrete in the floor-ceilings; acceptance of the facilities for "clean" installation work; acceptance of the facilities for "clean" finishing; acceptance of the administrative facilities for operative servicing or maintenance.

Entries in the operations log formalize the following events:

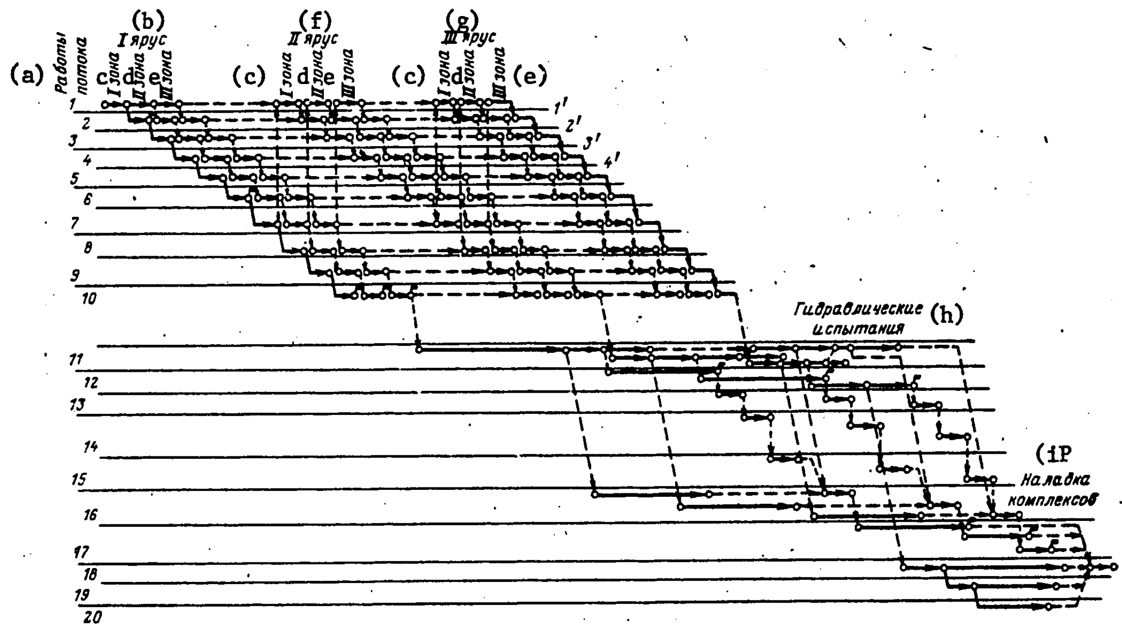
Completion of the reinforcing-form modules for installation of the special fittings in the walls;

Completion of foundations and structural elements for installation of equipment;

Completion of facilities for putting on the cover (after installation of equipment);

Completion of the reinforcing-form modules for installation of special fittings in the ceilings;

Completion of the facilities for finishing operations (after the concrete work);




| No on the figure | Flow Operations | Brigades performing the operations |
|---|---|---|
| 1 | Installation of reinforcing-form wall modules | All-around concrete workers |
| | Completion of the lining of the walls and floors. Forms. Reinforcing of the foundations for the process equipment | |
| 2 | Installation of especially complex fittings in the walls.* | Installation riggers |
| 3 | Pouring the concrete in the walls and foundations for the process equipment | All-around concrete workers |
| 4 | Installation of the basic and process equipment | Installation riggers |
| 5 | Installation of reinforcing-form modules for the floor-ceilings. Joining of the ceiling and wall linings | All-around concrete workers |
| 6 | Installation of especially complicated fittings in the floor-ceilings* | Installation riggers |
| 7 | Pouring the concrete in the floor-ceilings. Installation, inclusion of temporary heating and ventilation systems. Removal of forms, preparation of the structures for acceptance and cleanup | All-around concrete workers |
| 8 | Installation of scaffolding. Floating the concrete at individual points | All-around finishers |
| 9 | Installation of permanent lighting system. Installation of fasteners in the ceilings, walls and pipes in the floors | Installation riggers |

[Continued]

| No on the figure | Flow operations | Brigades performing the operations |
|---|---|---|
| 10 | Surface finishing, priming of the finished lining. Spackling. Priming of the ceilings and walls over the concrete. Removal of scaffolding. Laying of pipes in the floors. Execution of temporary drains in the floors. Removal of garbage and waste. Waterproofing of the floors. Installation of clean temporary floors (acceptance for "clean" installation) | All-around finishers and riggers |
| 11 | "Clean" heat installation operations | Riggers |
| 12 | "Clean" electric wiring, installation of monitoring and measuring equipment and dosimetry (acceptance for clean finishing) | Riggers |
| 13 | Repair of floor tie rods | All-around finishers |
| 14 | Laying of plasticized material | Plasticized material layers |
| 15 | Installation of scaffolding. Cleanup painting to one layer less than planned completion | All-around finishers |
| 16 | Heat insulation and lining | Insulation installers |
| 17 | Finish painting. Removal of scaffolding. Washing of plasticized material (acceptance of the administrative facilities for operativee servicing) | All-around finishers |
| 18 | Adjustment of the electrical section, the monitoring and measuring equipment and dosimetry | |
| 19 | Checking out the machinery | |
| 20 | Flushing, blowing down the circuits | |

*All of the fittings installed by the builders: the especially complicated fittings requiring high installation precision or special qualification are installed by the riggers and fitters.

Figure 6-4. PERT model of the flow-phase process of building a multilevel nuclear power plant structure
Zone I -- minimum required part of the enclosure, readiness of which opens up the front for the subsequent type of operations; zone II -- basic part of the enclosure; zone III -- part of the enclosure in which the completion of the given type of operation allows for proceeding with the completion of the subsequent type of operations

Key:
- a. Flow operations
- b. Level I
- c. Zone I
- d. Zone II
- e. Zone III
- f. Level II
- g. Level III
- h. Hydraulic tests
- i. Adjustment of complexes

Completion of the facilities for installation of lighting, installation of fasteners in the ceilings, walls and pipes in the floors;

Readiness of the facilities for priming;

Completion of hydraulic tests, clean finishing operations, laying plasticized material and transfer of scaffolding for completion of thermal insulation and lining;

Completion of thermal insulation and lining and transfer of the facilities for final painting.

All the remaining technical acceptances with notes in the logs and documents are formalized in accordance with the SNiP.

The analysis performed above of the special features of building nuclear power plants, their influence on the technology and organization of construction, practical checkout of the flow chart (sequence) of the operation has made it possible to discover the principal conditions of flow-phase construction of nuclear power plants:

The performance of concrete operations by the forces of the all-around brigades of concrete workers with the application of industrial methods of construction;

Inclusion of reliable heating and ventilation systems as the concrete operations are completed by levels or groups of facilities;

Performance of finishing operations by the forces of the all-around brigades of finishers;

Waterproofing of the floor-ceilings and organization of the drainage of water from them on all levels of the structure;

Separation of all of the facilities and groups and levels transferred as operations are completed to the corresponding responsible organizations and also insurance of cleanness and order in these facilities;

Delivery of the process equipment, instruments and cable products strictly on schedule;

Phasing of the execution of the construction and installation operations, a clear-cut system for monitoring and acceptance of these operations;

Control of the flow of operations by computer.

The obvious, although entirely necessary conditions of material-technical supply, provision with documents, and so on are not indicated among the flow conditions.

Process Sequence of Erection of the Main Facility

The placement of the cranes for nuclear power plants with VVER-440 reactor is illustrated in Figure 6-5. One version of the placement of the basic erecting cranes for erecting the main facility of the nuclear power plant with VVER-1000 reactor is shown in Figure 6-6. The plan for performing the operations provides for preparation of the envelope modules with lining and channel formers and other reinforcing-form modules on site.

The operations begin with the foundation plate, then the structures are erected for the reactor section first to the 12.3 meter level, then to the 37.8 meter level, and the installation of the shielding tank, the metal structural supports for the reactor takes place simultaneously, the supports are installed for the steam generators, the main circulating pumps, the expansion tank, the lines 850 mm in diameter, and so on. During the same period as the structural components are completed, the equipment is installed, and the cylindrical envelope is erected above the 12.3 meter level with installation of channel formers and welding of the lining. Then the bridge crane is installed, the pouring of concrete in the cylindrical part of the envelope is completed, and the cornice is built. The erection of the envelope dome begins with installation of its metal structures, reinforcing and pouring the concrete for the lower layer of the dome concrete. After installation of the channel formers and reinforcing, the subsequent concrete work on the dome is completed. The installation of the reactor vessel and other basic equipment is by bridge crane. At the same time, concrete operations are completed at the upper levels in the reactor section, and the stressed reinforcing of the envelope and dome is completed simultaneously.

For erection of the envelope the following process is adopted. After assembly of the reinforcing modules of the cylindrical part of the enclosure with the lining, control assembly of the modules in the working position on the annular wall is carried out, repeating the shape and dimensions of the reactor section. The pipe channel formers are installed. Then the modules are delivered to the reactor section where their installation takes place level by level. After the corresponding checkout of the installed modules, the welding is done and the tightness of the joints in binding is checked, the reinforcing of the structural components at the joints of individual modules are welded, and the pipe channel formers are finally connected and secured.

The channel formers for the stressed reinforcing must be sealed to prevent the cement mix from getting in them when pouring the concrete and to keep moisture from pitting the concrete during operation. The channel former material must insure minimum losses to friction when the reinforcing is put under tension. It is possible to use flexible metal sleeves and pipe made from polymer materials as the channel formers. It is expedient to use pipe made of incombustible polyethylene; otherwise during installation it is necessary to provide for safety measures to prevent combustion of the channel formers.

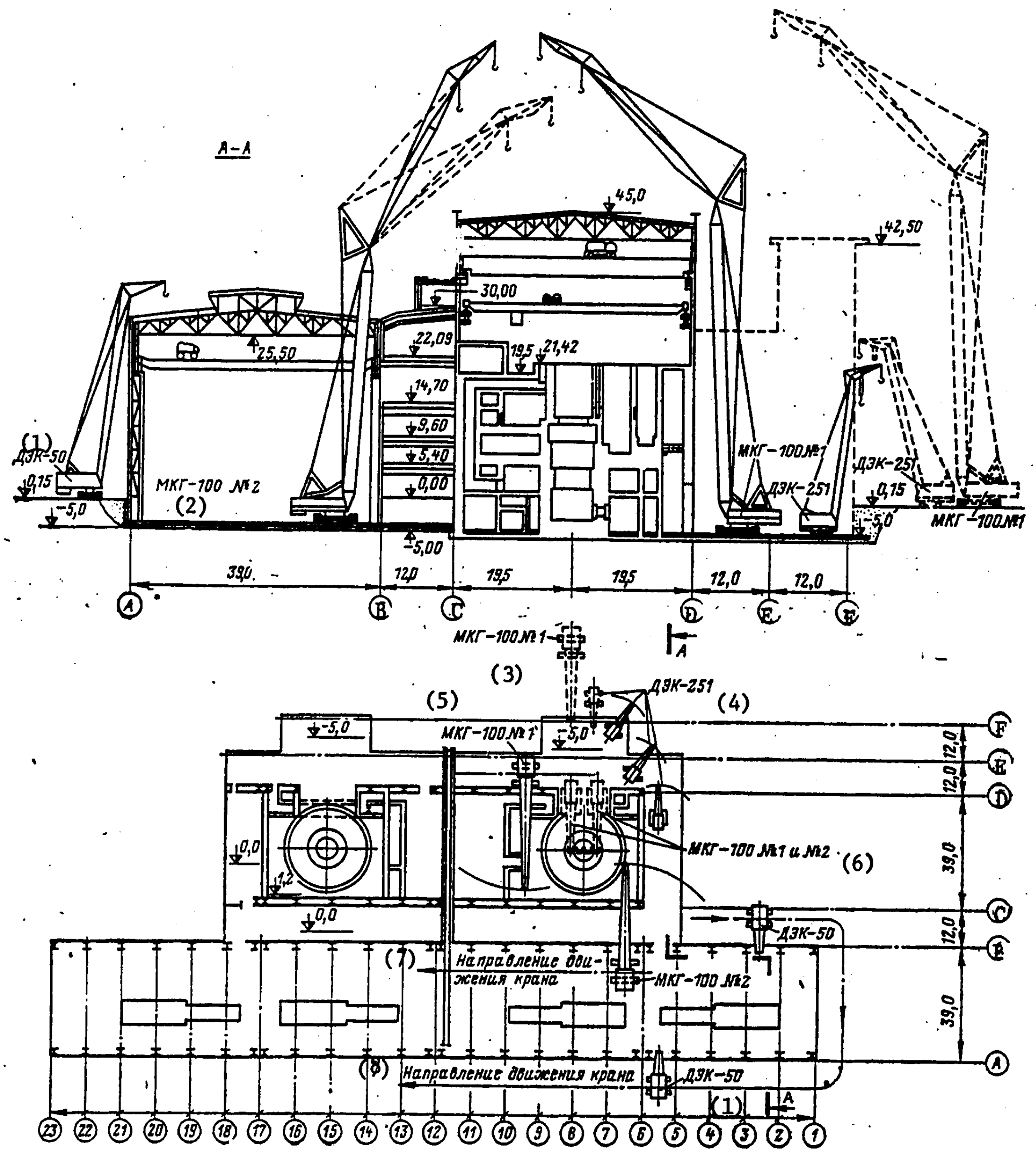



Figure 6-5. Diagram of the crane layout when building the main facility of the nuclear power plant with VVER-440 reactor

Key:

1. DEK-50
2. MKG-100 No 2
3. MKG-100 No 1
4. DEK-251
5. MKG-100 No 1
6. MKG-100 No 1 and No 2
7. Direction of movement of the crane
8. Direction of movement of the crane

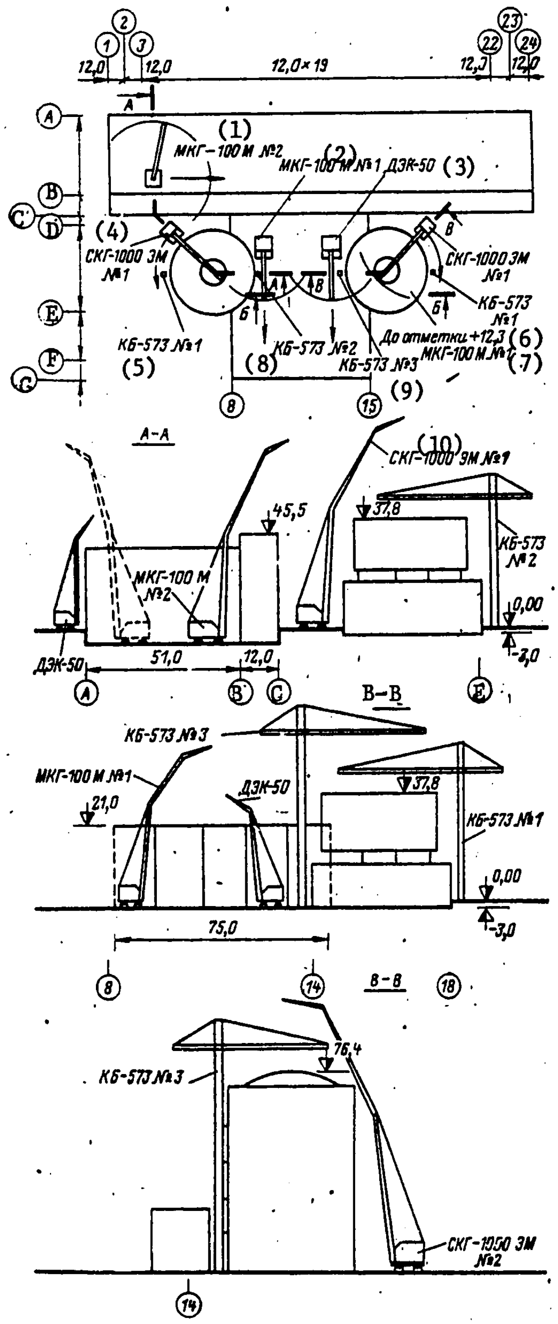



Figure 6-6. Crane layout for building the main facility of a nuclear power plant with VVER-1000 reactor

Key: 1 -- MKG-100M No 2; 2 -- MKG-100M No 1; 3 -- DEK-50; 4 -- SKG-1000 ZM; 5 -- KB-573 No 1; 6 -- to the +12.3 mark; 7 -- MKG-100M No 1; 8 -- KB-573 No 2; 9 -- KB-573 No 3; 10 -- SKG-1000 ZM No 1;

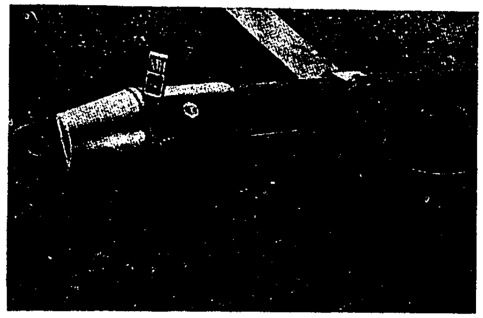


Figure 6-7. Head of bunched reinforcing with leader

The installed channel formers must be certified and stamped. In order to check the cross section of the tubes and preserve their walls after completion of installation of a group of channel formers, a control leader is lowered into them on a line, the diameter of the leader must be 4-5 mm larger than the diameter of the regular leader (Figure 6-7). This test is necessary in connection with the possibility of deformation of channel formers when pouring the concrete in the walls of the protective envelope.

The bunched reinforcing is pulled through the channel formers of the vertical walls of the envelope in the case of helicoidal (groove) reinforcing (see Figure 4-3) from the upper cornice by an electric winch with a line. The bunched reinforcing of the envelope is alternately put under tension by hydraulic jacks through one bundle from the top and from the bottom. The bunched reinforcing of the dome is stretched using a rigid wire. For prestressing of the bunched reinforcing at pilot nuclear power plants, powerful hydraulic jacks were used with a calculated stressing force of 10 MN (1000 tons) under a pressure of the working fluid in the hydraulic system of 40 MPa (400 kg/cm$^2$). The hydraulic jacks are installed on manipulators that move along the annular tracks of the lower gallery and the upper cornice at the joint of the dome to the vertical walls (Figure 6-8). The manipulators are self-propelled dollies with guides for installing the hydraulic jacks.

It is desirable to pour the concrete in the walls of the protective envelope using a sliding form which provides for continuity of the concrete work, a high rate of operations, the required quality of the seal of the concrete mix and smooth surface of the envelope.

The structural design of the sliding form provides for the possibility of disconnection and removal of any of its panels during pouring of the concrete in order to get around the numerous openings in the walls and corridors protruding beyond the basic dimensions of the envelope. For the normal rate of raising the form of 10-20 cm/hr the intensity of pouring the concrete mix in the envelope is 100-200 m$^3$ per shift. For lifting and distribution of the concrete mix around the perimeter of the structure, concrete pumps or cranes are used.

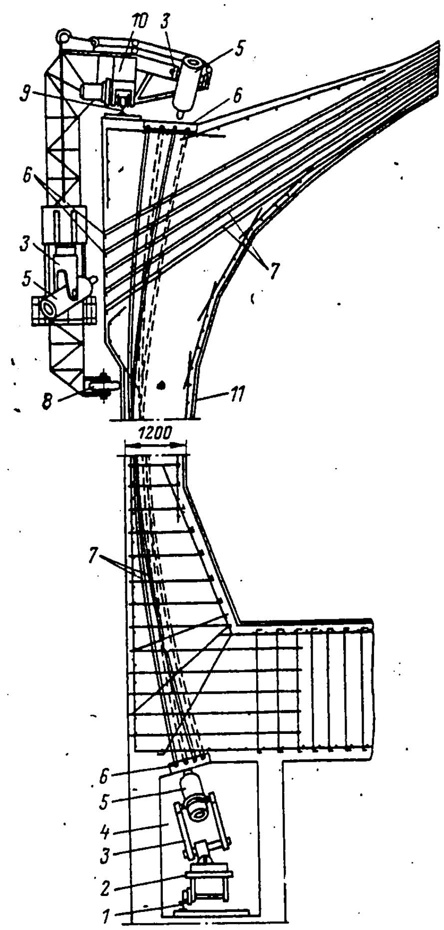



Figure 6-8. Mechanisms for putting the bunched reinforcing of the envelope under tension
1 -- lower annular track; 2 -- lower carriage; 3 -- manipulator; 4 -- jack gallery; 5 -- hydraulic jack; 6 -- anchor plates; 7 -- stressed bunched reinforcing; 8 -- supporting carriage; 9 -- top annular track; 10 -- top carriage; 11 -- inside lining

The next structure of the nuclear power plant with respect to complexity is the spetskorpus [specialized service building], which is a standard multistory structure. It is expedient to combine the work on it to the maximum with erection of the reactor section. However, the layout of the spetskorpus adopted at the first nuclear power plant does not permit them to be built completely simultaneously with the reactor sections, and their construction was done in phases.

The machine rooms are erected just as the machine rooms of thermal electric power plants, and therefore a description of these operations is not presented here.

The operations on the entire complex of structures of a nuclear power plant with two VVER-1000 power units and the sequence of performing these operations are presented in a complex, consolidated PERT model (Appendix 6-4).

One version of erecting the main facility with two RBMK-1000 reactors is shown in Figure 6-9. In the machine room and on the outside of the reactor section, two BK-1000 tower cranes are installed each. The "dead" zone formed here (not serviced by the BK-1000 cranes) is eliminated by installing KB-160-2 tower cranes successively at the 12.0 meter level (Figure 6-9, a) and the 49.0 meter level (Figure 6-9, b). The corresponding reinforcing of the floor-ceilings is provided for this purpose, and special structures are used at the 49.0 meter level to lay the crane tracks. The KB-674 crane installed on the foundation plate of block B performs the operations of erecting block C to the 41.0 meter level, after which it is erected from this position. In the first phase the blocks A and C are erected to the 12.0 meter level; in the second phase the same blocks are raised above the 12.0 meter level. As the cranes are released they are concentrated in block B. In the third phase operations are completed with respect to all blocks of the main facility.

The operations of the entire set of structures of the nuclear power plants with RBMK-1000 reactor and the sequence of performing them are shown in the PERT model (Appendix 6-5).

The construction rates of the main facilities can be increased significantly with the application of concrete pumps and also small tower and other cranes with increased speeds of raising the loads. In the performance plans, it is necessary to provide for independent operation of each partial flow. For this purpose each subgroup which makes up the partial flow must have its own machinery for vertical and horizontal transportation. At the present time light 4-10-ton KB-573 accessory cranes with 40-20 meter booms and lift speeds to 40 m/min and other cranes of suitable characteristics (see Table 6-5) are used for this purpose.

One of the main conditions of high-speed construction of nuclear power plants for which optimal loading of the cranes is insured is continuous and timely delivery of all of the structural components and process equipment to their operating zone. The use of industrial structural designs of monolithic biological shielding, the reinforcing-form modules with reinforcing plates (Figure 6-10) or three-dimensional reinforced concrete and steel cells (Figure 6-11, 6-12) and assignment of the cranes to the all-around brigades also create conditions for increasing the crane load.

Table 6-13 provides data on the attained load levels of machinery as applied to the structure of the operations of building thermoelectric power plants which are similar in structure to the operations on the nuclear power plants. An approximate estimate can be made of the crane requirement by dividing the total weight of the structural components which must be installed by crane (Table 6-14) by the construction time for these structures and the monthly crane loading norm.

It is simultaneously necessary to calculate the required number of workers defined as the ratio of the cost of the construction-' stallation operations to the planned output per worker. The distribution of the brigades by phases is calculated by the norms.

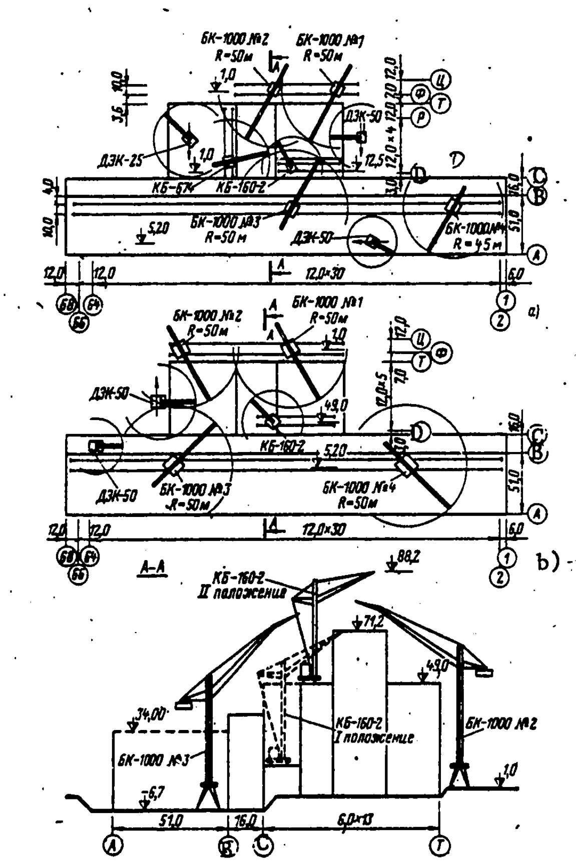


Figure 6-9. Diagram of the crane placement on the building site of the main facility of a nuclear power plant with RBMK-1000 reactors

Table 6-13. Crane Loading Level

| Type of crane | Maximum capacity, tons | Average monthly load, tons |
|---|---|---|
| Tower: | | |
| BK-1425 V | 60* | 1800 |
| BK-1000 | 50 | 1500 |
| Caterpillar: | | |
| MKG-100 | 40** | 1200 |
| DEK-50 | 50 | 1400 |
| DEK-25 | 25 | 750 |
| Other | 10 | 300 |

*With increased lift height of 116 meters.
**In the tower-boom execution

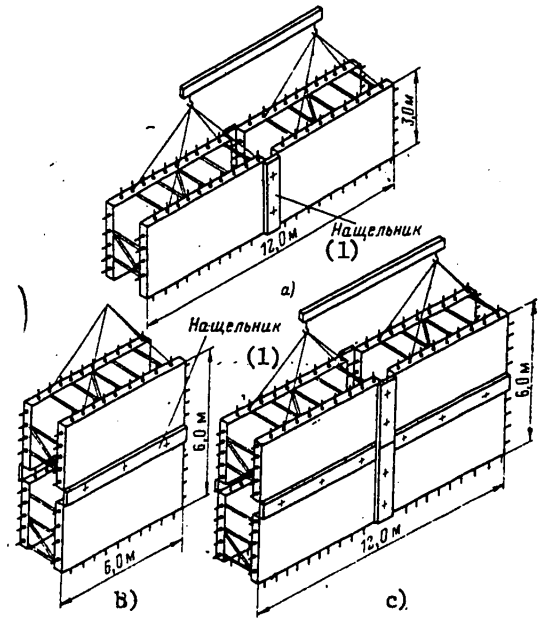



Figure 6-10. Reinforcing-form modules with reinforcing plates designed by the Gidroproyekt Institute, weighing 12 tons (a and b) and 24 tons (c)

Key:

1. Batten

The indicated calculations must be performed for each phase, estimating the technical and physical possibilities of the machinery and the working brigades. When details are necessary, the crane load can be calculated by the time norms for each phase considering the planned number of lifts for each crane.

Concrete Operations

The erection of radiation shielding is specific to the nuclear power plant. The components of the concretes used for radiation shielding are described in §5-3. The composition of the concrete must be determined by the calculated experimental method with mandatory checking of the operating composition of the sample mix in specialized construction laboratories, during the initial period of construction with use of a specialized organization.

The preparation of the concrete mixes is organized at the concrete construction plants. The concrete must be transported to the place where it is poured with minimum number of overloads. Especially heavy concrete is frequently moved in buckets picked up from trucks and sent to the locations where the concrete is poured by crane.

Table 6-14. Physical Volumes of Operations in Building the Main Facility of a Nuclear Power Plant

| Types of operations | with the RBMK-1000 reactor: Total | including: Block A | Block C | Block D | with VVER-1000 reactor: Total | Reactor section | Specialized service bldg. | Machine room and electrical equipment annex |
|---|---|---|---|---|---|---|---|---|
| Monolithic concrete and reinforced concrete, thousands, $m^3$ | 140,740 | 50,570 | 24,570 | 65,600 | 79,000 | 36,000 | 30,000 | 13,000 |
| Prefabricated concrete and reinforced concrete, thousands, $m^3$ | 26,000 | 3,830 | 2.670 | 19,500 | 14,000 | -- | 1,000 | 13,000 |
| Steel structural elements, thousands of tons | 15,600 | 5,000 | 1,000 | 9,600 | 8,700 | 4,000 | 0,700 | 4,000 |

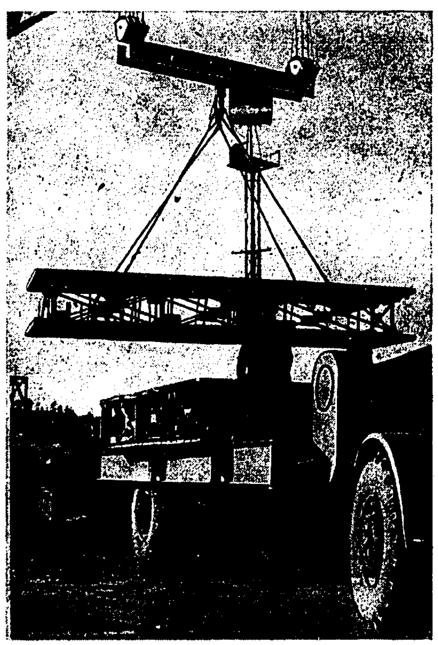


Figure 6-11. Reinforcing-form module with permanent reinforced concrete form (concrete cell)

Figure 6-12. Metal cell in which the lining is used as reinforcing and form

In case of the necessity for applying especially heavy concrete with a specific weight of about 5 tons/$m^3$, the process of separate pouring can turn out to be expedient -- first the fillers are put in, and then the mortar is pumped under pressure.

Before pouring the concrete mix in the structural element, the surface of the old concrete is prepared, there is technical acceptance of the reinforcing, the fittings and the forms, and the hidden operations are documented.

When performing concrete operations it is necessary to be guided by the SNiP III-15-76 and SN 156-67, to observe the general safety engineering requirements in accordance with SNiP III-A.11-70 and also the rules and instructions for safety engineering as applied to specific conditions.

The monolithic concrete and reinforced concrete are 70 to 75% of the total volume of the reinforcing concrete and concrete structural elements of the nuclear power plant. Large possibilities for industrialization of the construction of nuclear power plants and, on the basis of this, improvement of the quality of operations, reduction of the labor expenditures, cost and acceleration of construction are hidden in the improvement of the structural elements and the technology of the mass monolithic concrete work. Until recently, on some jobs and up to now the reinforcing of the reinforced concrete structures were performed by individual elements; then the fittings and the form were installed. The fittings were designed to protrude beyond the forms, and as a result of this, the application of a stock panel form was limited; frequently it was necessary to build the forms from boards on the job. The surface of the monolithic structural elements was of poor quality, requiring plastering. The labor consumption and construction times were large in this case, and the problem of creating industrial designs of nuclear power plants became obvious.

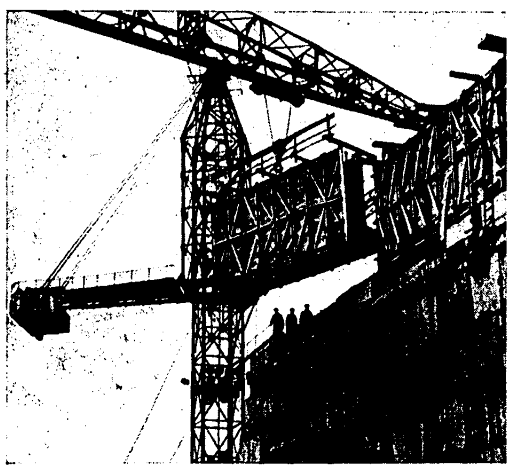


Figure 6-13. Reinforcing-forming modules with stock forms

At the present time experience has been accumulated in the use of reinforced concrete panels for these purposes, including the designed operating reinforcing, as envelope slabs, in particular, the hydroengineering construction. Frequently the assembly of fittings in the reinforcing frame modules were also introduced into the construction practice. The broad application of the prefabricated reinforced concrete in industrial and residential construction is generally known. The first experience in the industrialization of the design of the radiation shielding of nuclear power plants was realized on a broad scale in the construction of the Beloyarskaya Nuclear Power Plant [73], where prefabricated blocks weighing up to 15 tons were used for the walls of the reactor section. The prefabricated and combination (prefabricated monolithic) structural elements were used for walls with an insignificant number of fittings in order to avoid increasing the types and sizes of the prefabricated modules. The erection of the walls of such structures by the efforts of the complex brigades of concrete workers increased the rate of construction by 15%, the labor expenditures on the construction site were reduced by 4-5 times. At the same time, the cost of the biological shielding rose proportionately to the difference in prices of the prefabricated and monolithic reinforced concrete of the biological shielding.

In order to erect the monolithic structures, the reinforcing-form modules were used with complete prefabrication of the reinforcing and stack forms wrapped in roofing iron (Figure 6-13), which made it possible to reduce the plastering operations over the concrete, but it was not possible to completely exclude them. The application in the United States and England and other countries of forms made of form plywood (Figure 6-14) made it possible to do away completely with the plastering operations and has allowed conversion to painting the concrete structures without spackling, and where admissible, leaving the concrete surfaces without further finishing. At the present time for Soviet nuclear power plant construction, forms made of form plywood are recommended with fastening of the panels with anchor pins and blocking in the plane using boards (Figure 6-15).

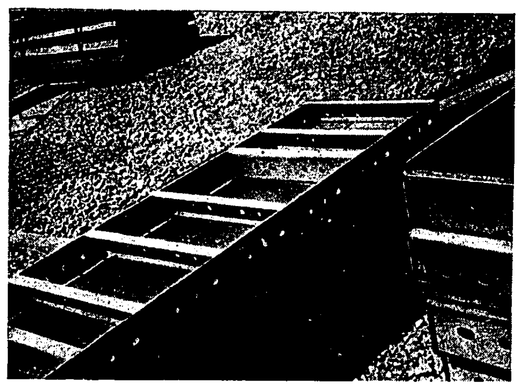


Figure 6-14. Panels of stock forms made of form plywood with the application of bent profiles

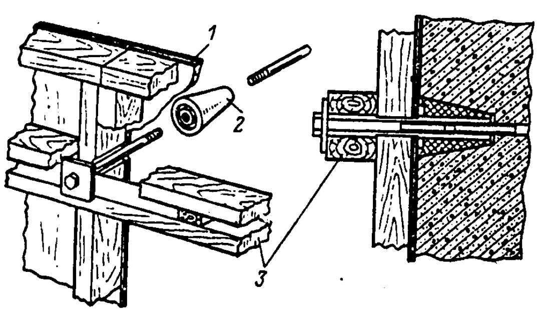



Figure 6-15. Fastening of stock form using anchor bolts and conical couplings
1 -- Form plywood; 2 -- conical plug coupling extracted from the concrete; 3 -- blocking boards

The generalization of the construction experience has made it possible to formulate the basic areas of development of the industrial methods of performing monolithic concrete work at the nuclear power plants which provide the basis for subsequent developments of reinforcing form modules.

1. In the detail designs of the monolithic reinforced concrete structures provision must be made for breakdown into reinforcing-form modules including the fittings. The structural designs of the reinforcing and the forms of all types for the modules are interconnected; therefore they must be developed jointly.

2. When designing the structural elements and the fittings it is necessary to strive to standardize the reinforcing-form modules with geometric dimensions and reinforcing and the fittings with respect to sizes and structural designs; the fittings must not protrude beyond the form.

3. The tolerances on installation of the massive fittings must be determined considering the actually necessary accuracy of installation in order to facilitate construction and reduce the expenditures of labor on installation of the fittings.

4. The structural designs of the reinforcing-form modules must begin with the expediency of their mass production at the plants or the regional bases.

5. It is necessary to organize the plant preparation of the reinforcing-form modules of optimal design and expand the production of the stock panel forms of efficient design.

6. It is necessary to develop measures to facilitate the transportation and pouring of the concrete mix by variation of the physical properties of the concrete and introduction of new machines and machinery.

In the German Democratic Republic at the Nord Nuclear Power Plant steel cells have been used for the first time which incorporate the lining sheets of the boxes as reinforcing and forms for the reinforced concrete structures (see Figure 6-12). A further development of the structural design of reinforcing-form modules was the spatial modules -- reinforced concrete cells with permanent form (see Fig 6-11) -- which were developed when building the Novovoronezh and Kola Nuclear Power Plants. These modules were provided for in the designs for nuclear power plants with water-cooled, water-moderated power reactors (VVER). The structural design and the process for assembly of such modules at the plants from separate plates with subsequent assembly into modules were developed.

The calculations demonstrated that the effectiveness of the three-dimensional reinforced concrete cell-blocks is especially large if their production is organized at the plants or the rayon bases.

Another version of the three-dimensional modules with reinforced concrete permanent forms is the standardized ribbed plates designed by the Gidroproyekt Institute [see Figure 6-10) used for nuclear power plants with RBMK reactors. These plates are made at the rayon bases. At the construction site the plates are assembled into modules, the fittings are installed and sealed (Figure 6-16). The protruding ends of the reinforcing of the modules are welded during installation.

The modules with permanent forms of both types have good outside surfaces of the concrete; they do not require plastering and they are suitable for painting without spackling.

The high quality of their surfaces is insured by forming on metal pallets or in forms. The cracks between the modules of both types are formed up ·ith battens.

The general requirements on the reinforcing-form modules for any . ructural element are the following.

1. Insurance of high quality of reinforced concrete structure and, in particular, the quality of the concrete surfaces, the savings of metal, reduction in cost, reduction in expenditures of labor at the construction site and total expenditures of labor and also reduction of the number of operations performed when assembling the module at height (at the concrete pouring location), which improved the conditions of labor and safety engineering.

2. The reliability and safety of transportation, storage and installation of the modules under different weather conditions.

3. Observation of tolerances when installing the fittings with respect to the axes and the reference marks of the structure: for all fittings (with the exception of special ones), in plan and with respect to height $\pm 50$ mm; the planes of the fittings from the plane of the wall $\pm 3$ mm; the axes of the rod and pipe corridors, the air ducts of the ventilation systems from horizontal 0.005 (5 mm per meter of length). The tolerances on installing the special fittings are specially stipulated in the detailed drawings of the corresponding divisions of the plan.

4. The painting of the concrete surfaces or lining of the modules at the plants.

The three-dimensional cell blocks cannot be used to replace the entire volume of monolithic reinforced concrete of the nuclear power plant; therefore the production of high-quality forms is urgent as before.

The transition to the industrial structural components of a nuclear power plant based on the development of plants and rayon bases for the production of these structural components and specialization of the subgroups with respect to complexes of concrete operations provide for a reduction in the expenditures of labor on concrete and plastering operations at the construction site by almost fivefold, and all labor expenditures considering the manufacture of the modules, almost cut in half. Here the labor consuming, dangerous work of the carpenters and the reinforcing rod handlers is facilitated, and it is to a significant degree replaced by the work of the riggers, and the conditions of labor and safety engineering are improved significantly.

The transportation and pouring of the concrete mix are highly labor-consuming operations. The system used is as follows: preparation of the concrete mix at the plant -- transportation by dump truck -- delivery to the location for pouring in a bucket by a crane -- pouring using a hopper with arm -- compacting by a vibrator -- is labor-consuming, it has become obsolete and must be replaced by the following system: the concrete plant -- concrete mixer truck -- concrete pump.

With this system the number of workers employed in transportation and pouring the concrete mix is reduced. However, for introduction of this system, it is necessary significantly to fill out the fleet with the concrete mixer trucks and concrete pumps.

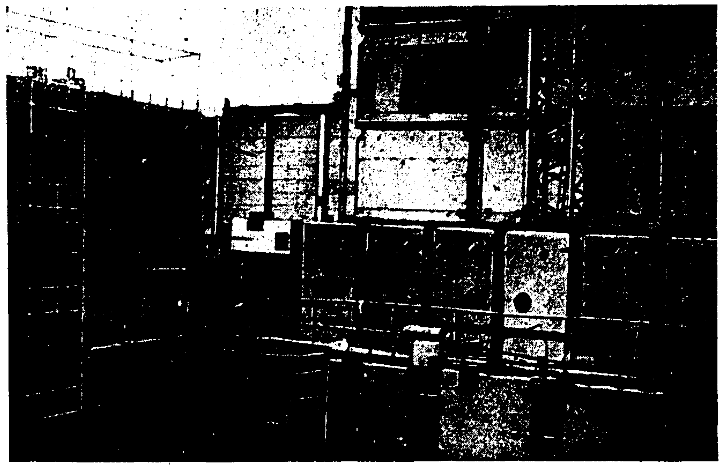


Figure 6-16. Reinforcing-form modules made of reinforcing plates of the Gidroproyekt Institute design with installed fittings

The physical properties of the concrete -- its convenience of pouring (mobility) and inclination to stratify (binding) to a significant degree determine the labor consumption of pouring in any, and especially strictly reinforced structures. In addition to the requirements on the physical-technical properties, requirements are imposed on the concrete which also depend on the quality of transportation, pouring and forming -- uniform density with respect to the entire mass (absence of cavities and the uniform distribution of filler) and a smooth surface without pits and air bubbles of the concrete structure. For satisfaction of these requirements it is necessary carefully to pack the laid concrete mix with vibrators and rodding. In the case of stratification of the concrete, a large filler is added to the zone where the concrete mix is separated. The highly mobile concrete mixes with the corresponding additives -- cast or high-plastic (with shrinkage of the columns of about 20 cm) have binding excluding stratification. Such concrete is laid in heavily reinforced structures without vibration, it flows around the reinforcing and fills all the cavities (the gravity method of pouring). For high quality of forms, the concrete is suitable for operating without painting or painting without spackling.

Cast concrete, which has the indicated properties is used abroad. In Soviet power engineering construction they have started to use cast concrete with a complex additive of 2-3% silica gel and 0.15-0.20% SDB of the waste in the cement (silica gel is a white finely disperse powder, which is the waste from producing aluminum fluoride). A search is being made for other additives. Cast concrete with complex additive corresponds to all the strength requirements, radiation resistance, frost resistance and water impermeability, imposed on the structural elements.

It is possible to use a complex additive also for especially heavy concrete.

When performing the concrete operations an important role is played by the geodetic service. The axes and levels of the parts of the structures, as they are erected, are coordinated with the axes (red lines) of the basic structures and the supporting network of the reference points, for which in the design provision must be made for a system of auxiliary points in plan view and height marks within the limits of the structures. The points are assigned on a full-scale by using geodetic markers (stakes, installed markers). The accuracy class of the breakdown of the axes and stakes is indicated in the design of the structure. Before beginning the construction and installation operations on the next level the installation of the required number of stakes and breakdown of the installation axes providing for conduct of the operations must be completed. All of the breakdown must be checked out and accepted by the committee with the participation of a representative of the thermal installation organization. The results of breakdown are formalized by a document approved by the chief construction engineer.

Anticorrosion Protective Coatings

The basic purpose of the anticorrosion protective coatings of nuclear power plants is to insure a normal radiationsituation and protect the structures from deterioration. The coatings must correspond to the requirements of deactivatability, chemical stability, service life under operating conditions, that is, radiation and mechanical stability and also aesthetic requirements. The coatings used at the nuclear power plants are presented in Table 6-15.

The lacquer and paint coatings put on the concrete surfaces and the plasticized coatings of the floors are used in less responsible, manned and semi-manned facilities. The paints and varnishes on carbon steel of the walls, ceilings, and floors are used in the semi-manned and unmanned facilities. Metal plating, paints and varnishes are used to increase the service life of the metal structures, access to which and the repair of which are complicated and also those operating under the conditions of effects from the air at increased humidity and temperature and the ionizing radiation flux. The polymer solution coatings are used for concrete floors of semi-manned and unmanned facilities. The protection by paints and varnishes of the equipment surfaces, the pipelines, the metal structural elements located in the facilities of the nuclear power plants is usually realized by the same paints as when coating the walls and ceilings of the corresponding facilities.

The operations with respect to protective coatings (preparation of the compositions, degreasing of the protective surfaces, application and drying of the coatings) are connected with explosionproofness and toxicity of the volatile sprayed materials; therefore they must be performed with strict observation of the Fire Safety Rules and the Rules for Safety Engineering and Production Sanitation and also auxiliary rules and instructions as applied to the specific conditions.

The operation with respect to the application of protective coatings must be performed by specialized organizations. In the necessary cases stock explosion-safe ventilation and lighting systems must be used for observation of maximum admissible concentrations of harmful agents in the air of the operating facilities in accordance with the requirements of the sanitary norms SN 245-71 and the designs of the production operations under complex conditions.

Before applying the protective coatings the services of the structural elements and equipment are subject to preparation. First of all the structural elements and equipment are mechanically cleaned of dirt, spills of mortar and concrete, rust, burrs from welding and also oil, and so on. The sharp edges and corners of the structural components are rounded. The metal lining of the walls and other structural elements in accordance with the engineering characteristics are subjected to sandblasting (using metallic sand or shot). After mechanical cleaning the dirt and dust are removed from the facilities by vacuum cleaners and wet rags. After shot blasting, the sheet metal must be degreased by an organic solvent. This operation is performed using stiff hair brushes. The surfaces of the concrete structural elements must be dry and dust-free; all of the construction and distillation operations to be performed in the stage of preparing the facilities must be completed. The degree of readiness of the facilities for production with respect to anticorrosion protection must be formalized by the corresponding document. In addition to the indicated requirements of flow-phase process when preparing for coating, it is necessary to be guided by the requirements of SNiP III-21-33, SNiP III-18-75, SNiP III-23-76.

In order to improve the quality of the operations and to improve the productivity of labor under the safest operating conditions it is necessary to provide for the performance of the largest possible volume of operations with respect to the coatings outside the construction site. It is recommended that the shot blasting of the lining and other metal structural elements, protection of them in accordance with the engineering conditions, preparation of paints, and partial coating with paints be transferred to the workshops and shops where preliminary preparation of the surfaces is organized.

The operations with respect to application of coatings are incompatible with the installation and welding operations in the same or adjacent facilities. This peculiarity requires strict observation of phasing of the operations and is an important additional condition of safety of finishing and installation operations.

During the process of preparing the compositions of paints and varnishes and the polymer solution coatings, there is periodic quality control of the compositions and correspondence of them to the technical specifications.

The paints and varnishes and polymer solutions, as a rule, are applied by mechanical means; the workers must wear respirators or diving suits. The application of individual layers of coating and drying take place at an average temperature of no less than +15°C and relative humidity to 75%. The deviations from these conditions are stipulated by the process instructions. When performing the operations of protecting the metal and concrete surfaces it is necessary to be guided by the requirements of production instructions and the SNiP III-16-73, SNiP III-21-73, SNiP III-23-76.

The metallized paint and varnish coatings are applied by the gas flame or electric arc method with the application of mechanical devices. Aluminum (metallized) is applied by spraying, and then the paint or varnish (epoxy EP-773, EP-525 or organosilicate AS-8a) is applied successively.

Table 6-15. Coatings for Protection of Structural Components and Equipment of Nuclear Power Plants

| Type of coating | Brand of coating | Protective surface |
|---|---|---|
| Paints and varnishes | Epoxy EP-273<br>Epoxy EP-569<br>Epoxy-silicone SP-ES-8 | Concrete and carbon steel linings of the walls, ceilings, floors, metal structural elements, equipment and pipelines |
| Metal plating and paints and varnishes (metal-polymer) | EP-525 epoxy or AS-8a organosilicate (with respect to aluminum metallization sublayer) | Carbon steel |
| Polymer solution | Epoxy-polyamide<br>Epoxy-oxyline | Concrete floors |
| Plasticized materials | Plasticized polyvinylchloride 57-48 | Concrete floors |

The lining with plasticized polyvinylchloride -- formula 57-40 -- is done to protect the concrete floors of the nuclear power plant facilities. The roll or sheet plasticized material 3-4 mm thick is welded by a jet of hot air using special torches with electric heaters or high-frequency welding. The cards (somewhat earlier than the welded sheets) are prepared in the workshop equipped with the corresponding benches, shears, presses and welders, at a temperature of about 20°C. The plasticized material is laid on a cement floor that has been primed with lime or a paint or varnish (to give the floors the necessary decorative appearance, for the plasticized material is transparent, and for protection of the floor concrete from liquid radioactive contamination if the plasticized coating is damaged). The plasticized material can be laid by complex groups of three-six people, within which there is a qualified electrician (he is not a plasticized material handler) and an expansion bolt fitter.

Large volumes of operations with respect to protective coatings and the lining of the boxes with steel require significant material and money expenditures. At the 6 million kilowatt nuclear power plants, more than 10,000 tons of sheet steel are requ_red for lining. At the present time scientific research work is being done to replace this short metal in the wall and ceiling linings with polymer solutions and polymer concrete. For coating the floors they have started to use new compounds based on epoxy resins (epoxy polyamide and epoxy oxyline). The use of cheap and available materials with low viscosity for the coatings permits mechanization of these operations and acceleration of the hardening process. The search for coatings must be combined with the problem of reducing toxicity and explosiveness of the sprayed materials.

Welding Operations

The metal structural elements and pipelines of nuclear power plants are made of carbon, low-alloy and high-alloy (corrosion-resistant) steels (Table 6-16 and 6-17).

Carbon steel VSt3sp is used for the circulating water and service water line, linings and other structural elements. Steel 20 is used for more responsible pipelines, the metal structural elements, tanks, and so on. Steel 22K is used to make the vessels of the steam generators and separators and also the primary layer of cladded pipe. The low-alloy steels 10KhSND and 1Kh2M are used to make structural elements and pipes for the nuclear power plant; steel 10KhSND is basically used to make vessel structures with sheet thickness to 40 mm. Corrosion-resistant 08Kh18N10T and 08Kh18N12T austenitic corrosion-resistant steel is widely used in the structural elements of pipes of nuclear power plants. The majority of process lines, the lining of the specialized facilities and various tanks are made from it.

Table 6-16. Chemical Composition of Steels Used at the Nuclear Power Plants

| Марка стали (1) | (2) Содержание, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | Cr | Ni | Ti | Cu | Mo | S | P |
| | | | | | | | | | (3) не более | |
| (4) ВСт3сп | 0,14—0,22 | 0,12—0,30 | 0,40—0,65 | — | — | — | — | — | 0,055 | 0,045 |
| 20 | 0,17—0,24 | 0,17—0,37 | 0,35—0,65 | <0,25 | <0,25 | — | <0,25 | — | 0,040 | 0,040 |
| (5) 16ГС | 0,12—0,18 | 0,70—1,0 | 0,9—1,3 | <0,3 | <0,3 | — | <0,3 | — | 0,040 | 0,035 |
| 22 К | 0,18—0,26 | 0,17—0,37 | 0,7—0,9 | <0,3 | <0,3 | — | <0,3 | — | 0,045 | 0,045 |
| (6) 10ХСНД | <0,12 | 0,8—1,1 | 0,5—0,8 | 0,6—0,9 | 0,5—0,8 | — | 0,40—0,60 | — | 0,040 | 0,040 |
| (7) 1Х2М | 0,08—0,12 | 0,17—0,37 | 0,40—0,70 | 2,0—2,5 | — | — | — | 0,60—0,80 | 0,020 | 0,025 |
| (8) 08Х18Н10Т | (3) Не более 0,08 | Не более 0,8 | 1,0—2,0 | 17,0—19,0 | 9,0—11,0 | 0,4—0,7 | — | — | 0,020 | 0,035 |
| (9) 08Х18Н12Т | Не более 0,08 (3) | Не более 0,8 | 1,0—2,0 | 17,0—19,0 | 11,0—13,0 | 0,3—0,6 | — | — | 0,020 | 0,035 |

Key:
1. Type of steel
2. Content, %
3. no more than
4. VSt3sp
5. 16GS
6. 10KhSND
7. 1Kh2M
8. 08Kh18N10T
9. 08Kh18N12T

Table 6-17. Mechanical Properties of Steels Used for Nuclear Power Plants

| Type of steel | Temporary resistance, MPa | Yield point, MPa | Relative elongation, % | Specific ductility, kilojoules/m² |
|---|---|---|---|---|
| | | no less than | | |
| VSt3sp | 380-490 | 240 | 27 | 800 |
| | no less than | | | |
| 20 | 420 | - | 28 | - |
| 16GS | 500 | 300 | 18 | 600 |
| 22K | 440 | 190 | 20 | 700 |
| 10KhSND | 540 | 400 | 19 | - |
| 1Kh2M | 400 | 300 | 20 | 1000 |
| 08Kh18N10T | 520 | - | 40 | - |
| 08Kh18N12T | 520 | 200 | 40 | - |

The sheet steel structural components are welded by automatic submerged arc welding or manual electric arc welding or argon-arc welding. A large amount of work is welding the linings of the specialized facilities. The linings are made of perlitic and austenitic sheet steel about 5 mm thick. The manufacture, installation and acceptance of the structural components of the linings are in accordance with SNiP 318-75.

Table 6-18. Quality Control of Welded Joints of Austenitic Steel Linings

| Category of welded joint | Method of welding | Methods and volume of control, %: External inspection and measurements | Internal flaw detection | Kerosene test[1] | Testing for resistance to MKK[3] and Metallography[2] |
|---|---|---|---|---|---|
| I | Automatic, semiautomatic, manual | 100 | 100 | 100 | 1/50 |
| II | Automatic, semiautomatic, | | 15 | 100 | 1/100 |
| | manual | 100 | 30 | 100 | 1/100 |
| III | Automatic, semiautomatic, manual | 100 | - | 100 | 1/200 |

Notes. [1]For one-way access to the welds, the kerosene test is replaced by the more labor-consuming and expensive vacuum method of control in the same volume.
[2]Measured by the number of indicators per running length of the weld in meters.
[3][intercrystalline corrosion].

There is a classification of lined structural elements by categories of welded joints:

| Category of welded joint | Lining structures |
|---|---|
| I | Bottom and wall of the holding and recharging basins; areas of the wells and tray of the core with height of edging 150-250 mm, in which temporary stagnation of an aggressive product is possible |
| II | Lining of the core facilities above the trays which can have short-term contact with aggressive solution during spilling or washing |
| III | Trays and lining of the walls of the facilities of the inactive zone |

Note. In practice more frequently austenitic steel is used for calculating I; austenitic steel or carbon steel with subsequent anti-corrosion coating is used for category II; carbon steel with subsequent anti-corrosion coating is used for category III.

Various structural elements and manufacturing process for the linings can be proposed, but preference must be given to the structural-process solutions which permit the performance of the largest possible volume of welding operations in the preinstallation operations shop (TsPR) with the application of automatic submerged arc welding and also provision of monitoring of all (or almost all) of the welds for seal using the kerosene test as the simplest and sufficiently reliable. For this purpose it is necessary to select the structural elements in the sequence of operations providing for access to the wells from both sides.

The usual methods of monitoring the welded joints of the linings are (Table 6-18): external inspection, flaw detection by x-radiation or gamma radiation exposure, monitoring of the tightness (the kerosene test or vacuum method), metallographic studies and testing for resistance to intercrystalline corrosion (MKK).

All of the wells are subjected to external inspection; the requirements on monitoring by external inspection are presented in Table 6-19.

The volume of monitoring by exposure to gamma or x-radiation is designated as a function of the categories of welded joints and the method of welding. Thus, for category II welded joints which are accessible or have limited access for repair (these include the greater part of the austenitic steel linings) executed by automatic welding, it is required to expose 15% to radiation examination; for those performed by manual energy arc welding, 30% of the length of the welds.

The requirements for flaw detection by exposure to gamma radiation are as follows:

| Defects | Admissible values |
|---|---|
| Cracks, gas pockets, and incompletely welded craters, a grid or chain of pores, slag or other foreign inclusions, poor penetration and faulty fusion between the beads | Not permissible |
| Individual pores, slag inclusions, tungsten inclusions | Permitted up to 15% of the thickness of the welded sheets, but no more than eight every 100 mm of weld |
| "Meniscus," internal concave bending of the root of the weld | Permitted to a depth of up to 15% of the thickness of the welded metal |

Note. The presence of several types of permissible defects with a total size with respect to depth of more than 15% of the thickness of the sheet in one cross section of the weld is not permitted.

Table 6-19. Requirements during Quality Control of Welds in the Austenitic Steel Linings by External Inspection

| Defects | Permissible defects in the welds by categories I | II | III |
|---|---|---|---|
| Cracks, runs, burns, incompletely fused craters, gas bubbles | Not permitted | Not permitted | Not permitted |
| Solid chain or grid of pores, poor penetration | Not permitted | Not permitted | Not permitted |
| Exit of the crater to the base metal, beginning of the weld (ignition of the arc) in the base metal | Not permitted | Not permitted | Not permitted |
| Three-dimensional defects of rounded or elongated shape (pores, slag and tungsten inclusions) | Not permitted | Not permitted | Individual pores and inclusions are permitted if their size is no more than 20% of the welded metal, but no more than 4 of them every 100 mm of weld |

[Table 6-19, contd]

| Defects | I | II | III |
|---|---|---|---|
| Gashes | Not permitted | Not permitted | Individual gashes are permitted to depth of up to 15% of the thickness of the welded sheet and up to 100 mm long but no more than 20% of the length of the given weld |
| Shift of the edges of butt welds, thinning of the edges of the sheets as a result of trimming before and after welding | Permitted to 10% of the thickness of the welded sheets | | |

The quality control of the welds in linings made of corrosion-resistant austenitic steels is in accordance with the Control Rules PK-010-62 and in accordance with the requirements of the flow charts.

High requirements on the quality of the welded joints of the majority of pipelines of nuclear power plants and the location of many of the welded joints at places that are difficult of accesss for manual welding techniques give rise to the necessity for broad application of automatic welding. The most widespread is non-consummable electrode, gas-shielded automatic welding (primarily argon-shielded), as insuring high properties of the welded joint and good continuity of the weld and permitting comparatively easy automation of the welding process in all spatial positions. Automatic argon arc welders have been built for nonrotating joints of pipe of different diameters (from 14 to 550 mm) and also for tack welding the connecting pipes (process channels) to the reactor covers. The ODA, TAM and GNS automatic welders of different types and sizes are designed for butt welding of pipe from 10 to 250 mm in diameter, the ASTM-6 (Orgenergostroy Institute Design) and AT-159-ShM (Tsentrenergomontazha Institute Design) automatic welders are for butt welding of pipe 159-150 mm in diameter, the APT-1M (Orgenergostroy Institute Design) automatic welder is for tack welding of connecting pipes 133 mm in diameter to the reactor covers. The APT-1M automatic welder offers the possibility of both gas-shielded and submerged arc welding. The edges of the pipe are prepared for welding in accordance with the requirements of OP1513-72.

Quality Control of Operations

In all phases of construction of a nuclear power plant the contract organization must organize systematic operation by operation and acceptance quality control of the construction materials, products and operations in accordance with the requirements of the design, the standards, construction rules, instructions and engineering specifications for performance of operations. For constant quality control the general contractor organizes a technical inspection unit (quality inspection unit), a construction materials laboratory and geodetic service.

The basic goals of the engineering inspection team are preventive measures which prevent low-quality performance of operations and the monitoring and technical inspection of the quality of performing the construction-installation operations.

The building materials laboratory realizes the selection and monitoring of the compositions of concretes and mortars, the compositions of the insulating and other materials, testing of materials, intermediate products and products from the beginning of the erection of the nuclear power plant, selective quality control of the construction-installation operations, the production output and also it systematically sees that the rules for storing materials, structural elements, products and parts are observed.

The main goals of the geodetic service in construction are performance of the set of geodetic operations providing for exact correspondence of the full-scale erected structures to the design and also geodetic monitoring of the construction process. The geodetic service must provide, in particular, for the performance of geodetic breakdown operations when the basic design dimensions and height marks of the structures are carried over to full scale, and the instrument monitoring of the correctness of the performance of construction-installation operations.

The quality control of operations performed by the specialized subcontracting organizations must be realized by the control services created with respect to the clarification of these organizations.

The management of a nuclear power plant under construction monitors and conducts a technical inspection of the construction process for correspondence of the performed operations to the requirements of the detailed drawings, the effective instructions, technical specifications for performance of operations and the SNiP.

The general design organization on its part realizes the author's inspection of quality of operations at the construction site with respect to erecting the nuclear power plant structures.

The activity of all of the control services is an inseparable component part of the construction process and must provide for improved quality, reduction of cost and reduction of duration of construction.

Intermediate acceptance and acceptance of the finished structural components and structures of the nuclear power plant must be in accordance with the design and SNiP requirements for the corresponding types of operations. On acceptance by a committee made up of representatives of the plant, the general designer and the construction organization (general contractor) documents are filled out with indication of the performed operations and their quality. The hidden operations must be documented by the committee made up of representatives of the client and the construction organization. The specifications and formulas must be appended to the documents for the hidden operations.

The quality control of materials, products and structural components entering into the construction of a nuclear power plant and also the performed operations are realized in accordance with the design requirements, the requirements of the SNiP, All-Union State Standards and TU [technical specifications] for individual types of materials.

The materials for preparing the concrete and mortar and also materials used for reinforcing the reinforced concrete structures must satisfy the requirements of the SNiP I-V.2-69, SNiP II-21-75, SNiP III-15-76, SNiP II-V.3-72, SN 482-76 and the corresponding All-Union State Standards.

The quality control and evaluation of concrete and reinforcing operations and also the operations with the application of especially heavy, hydrate and heat resistant concretes and concretes for increased temperatures must be performed in accordance with the requirements of SNiP III-15-76, the corresponding All-Union State Standard and other normative materials.

The materials used for specially heavy, hydrate, heat resistant concretes and concretes for increased temperatures, in addition to the general requirements, must satisfy the requirements stipulated in the design and the following additional requirements:

Magnetite, hematite and ilmenite ores must contain more than 30% iron (by weight); barite ore must correspond to All-Union State Standard 4682-74, and cast iron and steel shot must correspond to All-Union State Standard 11964-66;

Serpentinite fillers for hydrate concretes must correspond to TU 95-6112-76 of the Uralasbest; limonite ores must contain more than 30% by weight iron and chemically bound water of more than 10% by weight; natural boron-containing compounds must contain more than 10% by weight boron, less than 1% by weight sulfur compounds; synthetic boron-containing compounds (boron carbide, borated chamotte) must correspond to GOST-5744-74 GOST-1598-75 and GOST 390-69;

The fillers for the concretes used at increased temperatures must satisfy the requirements of SN 156-67, and the finely ground additives, in addition, the requirements of SniP I-V.2-69 and local technical specifications.

The quality control of materials for preparing especially heavy, hydrate, heat-resistant concretes and concretes for increased temperatures must be performed by the methods discussed in the standards and technical specifications for these materials and also in accordance with the following GOST [All-Union State Standard]: 15053-77, 2211-65, 2409-67, 12761-67, 12747-67, 12760-67, 12763-67, 12750-67, 5744-74, 2642-71, 17496-72, 3647-71, 4069-69 and local technical specifications.

For quality control of heat-resistant concretes the refractoriness must also be defined according to All-Union State Standard 4069-69; compressive strength after heating to operating temperature according to All-Union State Standard 4071-69.

During pouring of the concrete mix into the protective structures of the nuclear power plant, primarily the especially heavy concrete, it is recommended that the density and uniformity of the concrete mix be checked selectively by determining the specific weight by the radio isotopic method according to All-Union State Standard 17623-72.

When pouring the concrete and when performing quality control on the finished structures it is necessary to check the presence of cavities behind the lining by a radioisotopic instrument and the specific weight of the especially heavy concrete according to All-Union State Standard 17623-72.

The cavities exceeding 5% of the thickness of the concrete wall are subject to finishing.

The quality control and evaluation of the primer must be made in accordance with SNiP III-19-76 and the All-Union State Standard for the corresponding types of primer testing.

The quality control and estimation of wooden structures with antiseptic and fire-proof treatment at the building site are carried out in accordance with SNiP III-19-75 and the corresponding All-Union State Standards.

The materials used for waterproofing operations must satisfy the requirements of SNiP III-20-74, SN 301-65, and the All-Union State Standards for the corresponding materials.

The quality control and evaluation of waterproofing operations must be performed in accordance with SNiP III-20-74.

The heat insulating materials must satisfy requirements SNiP III-20-74 and the All-Union State Standards for the corresponding materials.

Quality control and evaluation of the heat insulating operations must be performed in accordance with SNiP III-20-74.

When performing the welding operations, the following types of control must be realized: the entrance control of the materials (before welding); operation-by-operation control during performance of the welding operations; quality control of the completed welds.

The quality control of the welded joints of the structural elements and equipment, the subcontrol Gosgortekhnadzor of the USSR must be realized in accordance with the control rules PK 1514-72 jointly with the "Rules for the Design and Safe Operation and Maintenance of the Equipment of Nuclear Power Plants, Experimental and Research Nuclear Reactors and Devices."

The methods, the volumes of control and the category of the welded joints, equipment and pipelines and also the norms for quality estimates must be designated by the detailed drawings or by the control charts considering the requirements of the control rules PK 1514-72, PK-03TsS-66, SNiP III-18-75 and the instructions discussed below.

The quality control of the welded joints of the reinforcing and the fittings must be carried out according to the Welding Instructions SN 393-69.

Metallographic studies are performed in accordance with PK-1514-72 and the requirements of the process instructions. The tests for resistance to intercrystalline corrosion of the welding joints must be performed in accordance with All-Union State Standard 6032-75.

The quality estimate of the welded joints is made on the basis of the result of monitoring methods established for the given welded joints by drawings, quality charts or other effective normative documents.

The quality of the welded joints and the surfacing for welding on the structural elements and pipes must be considered unsatisfactory if for any type of monitoring internal or external defects are detected in them which go beyond the limits of the norms established by the "Control Rules," corresponding SNiP and production instructions.

All the results with respect to quality control of the welded joints must be indicated in the "Journal for Quality Control of the Welded Joints" of defined form.

The quality of the anti-corrosion protective coatings is monitored in accordance with the SNiP III-23-76. The quality of the materials and the tank compositions, quality of preparation of services, the sequence of applying the coatings, the conditions of drying each layer, the quality of the individual layers (thickness, uniformity, absence of leaks, poor paint coverage, foreign inclusions) and the protective coating as a whole (total thickness, adhesion, continuity) are subject to control.

The paint and varnish coatings are checked visually -- each layer according to the indicated All-Union State Standard 6992-68; the thickness of the coatings with respect to the metal, by thickness gauges, and with respect to concrete, by control notching. The binding of the paint and varnish coating to the base is controlled according to All-Union State Standard 15140-69. The drying time for each coat and the coating as a whole must correspond to the requirements of the All-Union State Standard 19007-73, the technical specifications and the process instructions. The solidness of the coating must be checked visually.

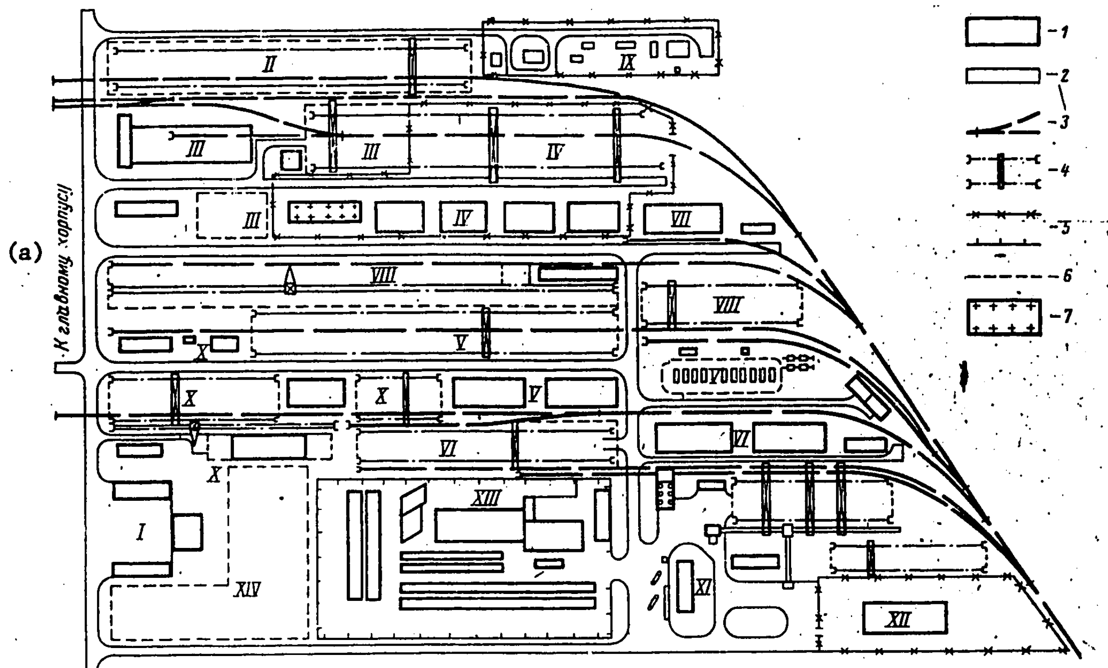
The metallized coatings must be monitored during preparation of the surface for metallizing, during the process of applying the coating, then the quality of the finished product is checked, in particular, the strength of adhesion to the base. The thickness of the applied metallized layer is checked by the instruments ITP-I or TPN-IV.

The surface quality is checked by comparison with a standard. The strength of adhesion to the base is checked by tapping with a wooden hammer (there should be no chatter). The defective sections are removed and recoated.

The plasticized floors using polyvinylchloride, formula 57-40 are checked visually. The welded joints, in addition, can be checked by electrospark defectoscopes and mechanical testing of the control samples according to All-Union State Standard 11262-76.

APPENDICES

Appendix 6-1. Construction Base of a Nuclear Power Plant with VVER-1000 Water-cooled, Water-Moderated Power Reactor




Key: a. to the main facility

Layout of the temporary building and structures

I -- administrative and general services complex
II -- section for assembling structural elements
III -- section for installing thermomechanical equipment
IV -- administrative storage areas
V -- construction storage areas
VI -- wiring operation section
VII -- chemical protection and thermal insulation section
VIII -- cooling tower construction section
IX -- gas supply facilities
X -- reinforced decking unit

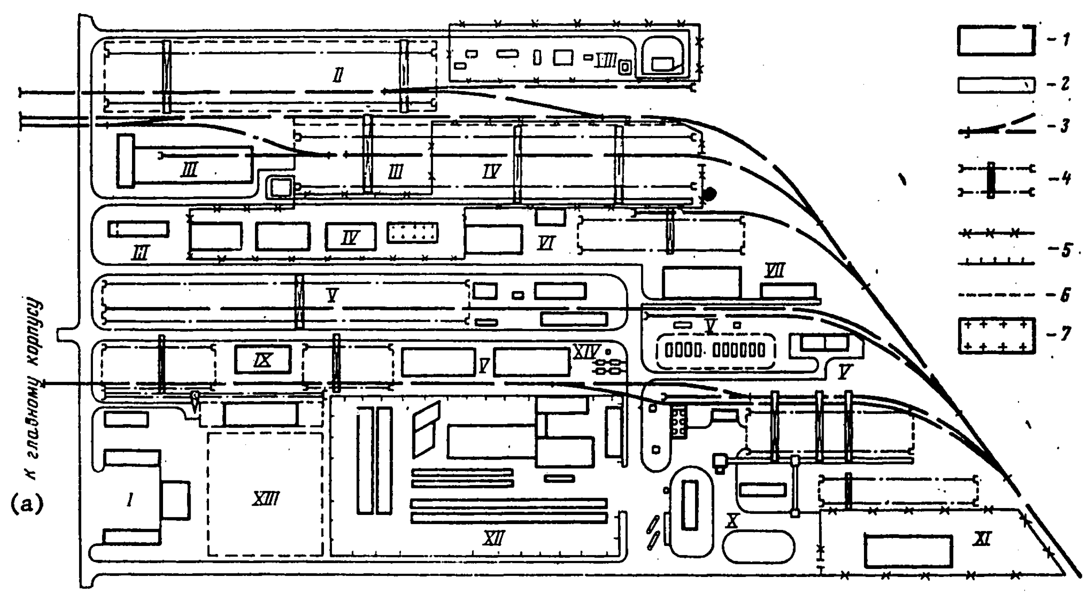
XI -- concrete services
XII -- mechanical repair services
XIII -- motor pool
XIV -- section for location of mechanized columns

Provisional notation: 1 -- buildings; 2 -- roadways; 3 -- railroads; 4 -- crane tracks; 5 -- enclosure; 6 -- section boundary; 7 -- shed.

Technical-Economic Indices

| | |
|---|---|
| Construction base area, hectares | 33.50 |
| Area covered with buildings and structures, $m^2$ | 2132 |
| Open storage areas and assembly-consolidation areas, hectares | 8.02 |
| Other structures, hectares | 4.972 |
| Length of roadways, km/hectare | 4.28 |
| Railroads, km/hectare | 6.05 |
| Crane tracks, km/hectare | 2.36 |
| Total covered area, hectares | 23.70 |
| Use factor of the territory, % | 70.6 |

Appendix 6-2. Construction Base of a Nuclear Power Plant with VVER-440 Reactor




Key: a. to the main facility

Layout of Temporary Buildings and Structures

I -- administrative and general services complex
II -- section for assembling structural elements
III -- section for installing thermomechanical equipment
IV -- administrative storage areas
V -- construction storage areas
VI -- wiring operation section

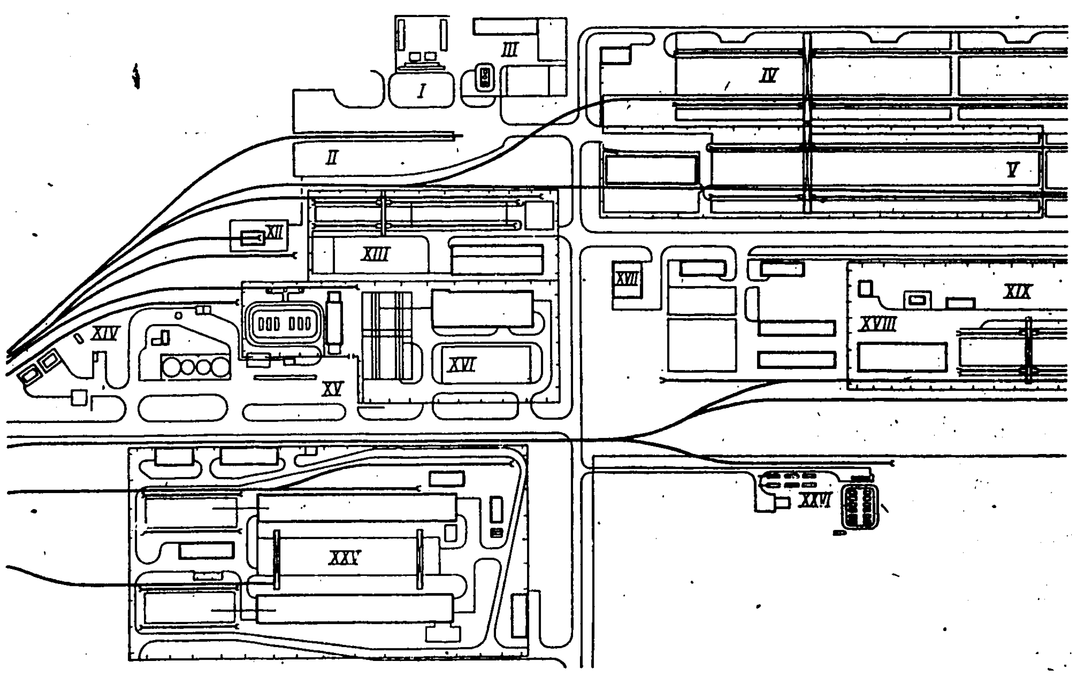
VII -- chemical protection and thermal insulation section
VIII -- gas supply facilities
IX -- reinforced decking unit
X -- concrete services
XI -- mechanical repair services
XII -- motor pool
XIII -- section for location of mechanized columns
XIV -- other structures

Provisional notation: 1 -- buildings; 2 -- roadways; 3 -- railroads; 4 -- crane tracks; 5 -- enclosure; 6 -- section boundary; 7 -- shed.

Technical Economic Indices of the Listing Assignment

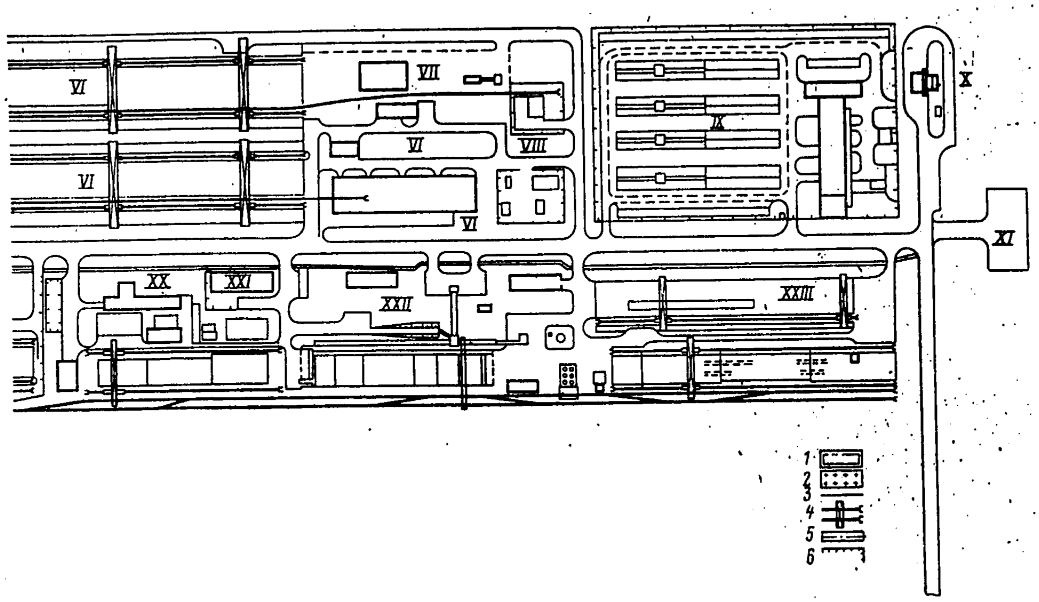
| | |
|---|---|
| Construction base area, hectares | 29.1 |
| Area covered with buildings and structures, $m^2$ | 2132 |
| Open storage areas and assembly-consolidation areas, hectares | 5.27 |
| Other structures, hectares | 4.969 |
| Length of roadways, km/hectare | 3.51 |
| Railroads, km/hectare | 5.3 |
| Crane tracks, km/hectare | 1.40 |
| Total covered area, hectares | 20.70 |
| Use factor of the territory, % | 71.2 |

Appendix 6-3. Construction Base of a Nuclear Power Plant with VBMK-1000 Reactor



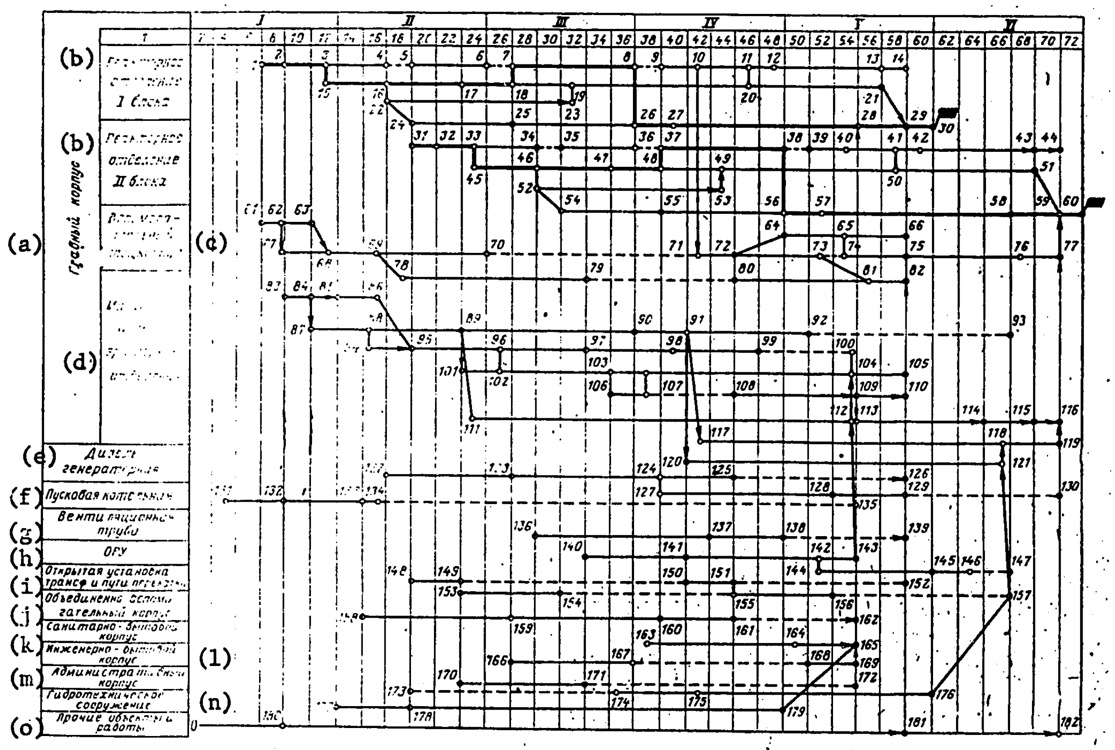
Layout of temporary buildings and structures

I -- 110/6 kv substation
II -- rock and crushed rock storage
III -- main power engineering base
IV -- section for erection of structural elements
V -- administrative storage area
VI -- section for installing thermomechanical equipment
VII -- chemical protection section
VIII -- gas supply facility
IX -- truck and tractor base
X -- washing
XI -- administrative and construction management building
XII -- locomotive depot
XIII -- wiring operation sections
XIV -- asphalt concrete services
XV -- fuels and lubricants storage
XVI -- construction mechanization base
XVII -- dining room
XVIII -- heat insulation operations
XIX -- construction storage areas
XX -- woodworking shop
XXI -- dining room
XXII -- mortar services
XXIII -- prefabricate reinforced concrete area
XXIV -- reinforcing services
XXV -- prefabricated-collapsible housing construction plant
XXVI -- mobile boiler



Provisional notation: 1 — buildings and structure; 2 — sheds; 3 — temporary railways; 4 -- crane tracks; 5 — roadways; 6 — enclosure.

Appendix 6-4. PERT Chart for the Construction of Nuclear Power Plants with VVER-1000 Reactor




Key:
- a. main facility
- b. reactor division of block ...
- c. auxiliary specialized facility
- d. mechanical and deaerator divisions
- e. diesel generator
- f. starting boiler
- g. vent pipe
- h. outdoor distribution station
- i. outdoor transfer station
- j. associated auxiliary service facility
- k. sanitation and general services facility
- l. engineering and general services facility
- m. administrative building
- n. hydraulic engineering structure
- o. other facilities and operations

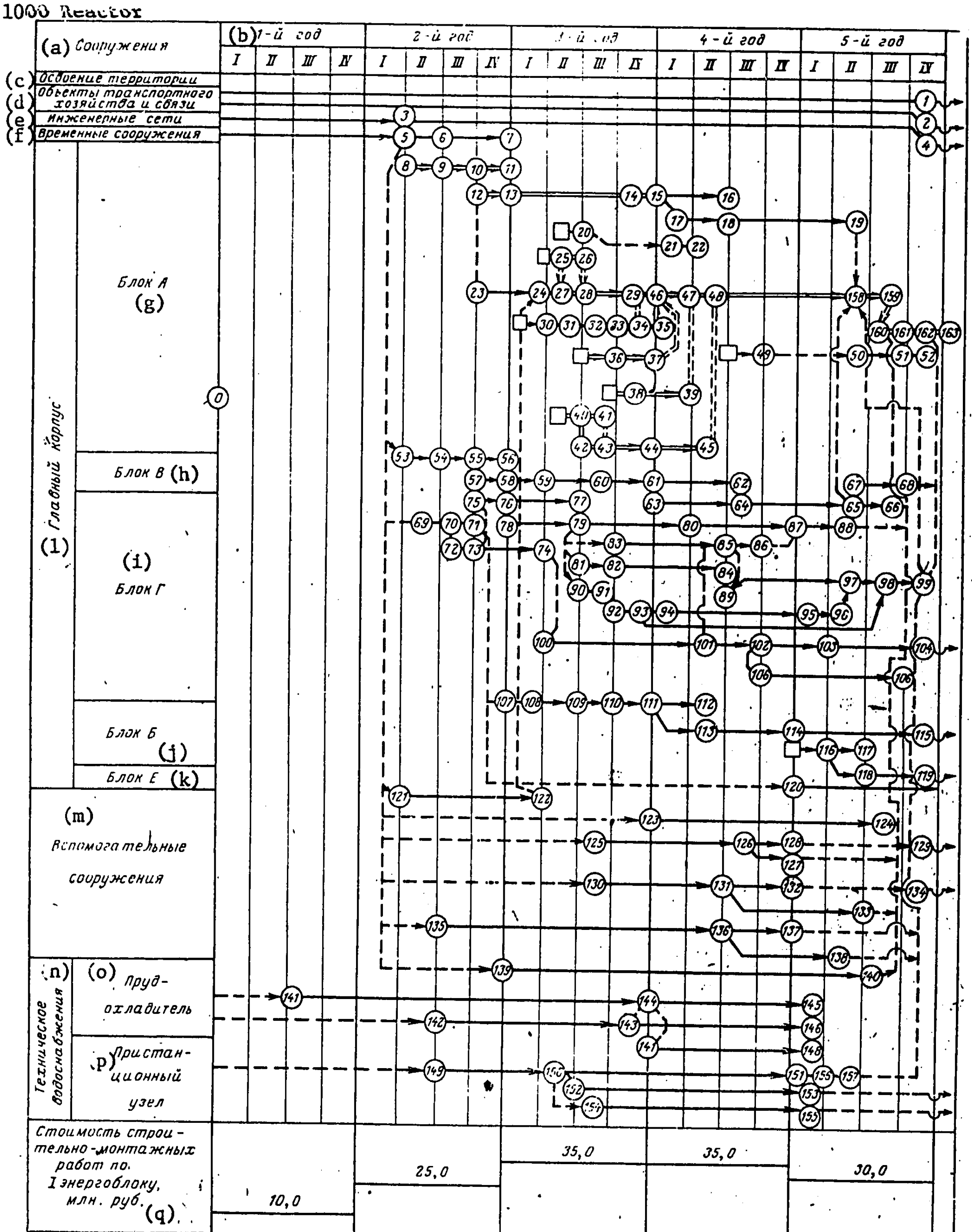
| Chart position | Types of operations |
|---|---|
| Reactor division of block I | |
| 1-2 | Excavating the foundation |
| 2-3 | Erecting the lower slab |
| 4-6 | Erecting outside wall |
| 7-9 | Erecting the cylindrical part of the envelope to the cornice |
| 9-10 | Erection of cornice |
| 10-11 | Erection of the dome, first phase |
| 11-12 | Erection of the dome, second phase |
| 12-13 | Tension on the bunched reinforcing of the envelope |
| 13-14 | Molding the envelope |
| 15-16 | Erection of the inside structures to the 9.3 meter mark |
| 16-17 | Erection of floors and ceilings to the 11.8 meter mark |
| 17-18 | Erection of inside structures to the 22.8 meter mark |
| 18-19 | Erection of inside structures to the 38.1 meter mark |
| 19-20 | Finishing operations above the 12.3 meter mark |
| 20-21 | Finishing |
| 22-23 | Finishing operations to the 9.3 meter mark |
| 24-25 | Installation of equipment and pipelines below the 9.3 meter mark |
| 25-26 | Rigging and installation of equipment above the 12.3 meter mark |
| 26-27 | Installation of 400 ton crane |
| 27-28 | Installation of equipment and pipes |
| 28-29 | Starting and adjustment operations |
| 29-30 | Physical starting, power production starting |
| Reactor division of block II | |
| 31-32 | Excavation of foundation |
| 32-33 | Erection of lower slab |
| 33-34 | Erection of outside walls to the 9.3 meter mark |
| 35-36 | Ereection of outside walls to the 18.14 meter mark |
| 37-38 | Erection of the cylindrical part of the envelope to the cornice |
| 39-40 | Erection of cornice |
| 40-41 | Erection of dome, first phase |
| 41-42 | Erection of dome, second phase |
| 42-43 | Tension on the bunched reinforcing of the envelope |
| 43-44 | Molding the envelope |
| 45-46 | Installing inside structures to the 9.3 meter mark |
| 46-47 | Erection of floors and ceilings to the 11.8 meter mark |
| 47-48 | Erection of inside structures to the 22.8 meter mark |
| 48-49 | Erection of inside structures to the 38.1 meter mark |
| 49-50 | Finishing operations above the 12.3 meter mark |
| 50-51 | Finishing |
| 52-53 | Finishing operations to the 9.3 meter mark |
| 53-54 | Installation of equipment and pipelines below the 9.3 meter mark |

| | |
|---|---|
| 55-56 | Rigging and installation of equipment above the 12.3 meter mark |
| 56-57 | Installation of 400 ton crane |
| 57-58 | Installation of equipment and pipes |
| 58-59 | Starting and adjustment operations |
| 59-60 | Physical starting, power production starting |
| | **Auxiliary specialized facility** |
| 61-62 | Excavation of foundation, first phase |
| 62-63 | Excavation of foundation, second phase |
| 64-65 | Installation of structural elements of the III swath of the first phase |
| 65-66 | Installation of structural elements of III swath of the second phase |
| 67-68 | Erection of the lower slab, first phase |
| 68-69 | Erection of the lower slab, second phase |
| 69-71 | Installation of structural elements of swath I |
| 71-74 | Installation of structural elements of swath II |
| 74-75 | Installation of first phase swath III equipment |
| 75-76 | Installation of second phase swath III equipment |
| 76-77 | Starting and adjusting operations of block II |
| 78-80 | Rigging and installation of equipment of swath I |
| 80-81 | Rigging and installation of equipment of swath II |
| 81-82 | Starting and adjustment operations of block I |
| | **Machine room and deaerator division** |
| 83-84 | Excavating the foundation of block I, phase 1 |
| 84-85 | Excavation of foundation of block I, phase 2 |
| 85-86 | Excavation of foundation of block II |
| 87-88 | Laying the foundation of the block I building |
| 88-89 | Installation of the frame and enclosing structures of block I, phase 1 |
| 89-90 | Installation of framing and enclosures of block I, phase 2 |
| 90-91 | Installation of framing and enclosing structures of block II, phase 1 |
| 91-92 | Installation of framing and enclosing structures of block II, phase 2 |
| 94-95 | Laying the foundation of the block II building |
| 95-96 | Laying the foundation for the turbogenerator No 1 |
| 96-97 | Laying the foundation of the turbogenerator No 2 |
| 97-98 | Laying the foundation for turbogenerator No 3 |
| 98-100 | Laying the foundation for turbogenerator No 4 |
| 101-102 | Installation of crane No 1 |
| 102-104 | Installation of auxiliary equipment and pipelines of block I |
| 104-105 | Washing, blow down and testing |
| 106-107 | Installation of 125 ton crane No 2 |

| | |
|---|---|
| 108-109 | Installation of turbogenerator Nos 1 and 2 |
| 109-110 | Hydraulic testing |
| 111-112 | Installation of equipment and lines of the deaerator stack of block I |
| 113-114 | Installation of turbogenerator Nos 3 and 4 |
| 114-115 | Hydraulic testing |
| 115-116 | Testing |
| 117-118 | Installation of auxiliary equipment and lines of block II |
| 118-119 | Washing, blowdown, testing |
| 120-121 | Installation of equipment and lines of the block II deaerator stack |
| | **Diesel generator** |
| 122-123 | Construction operations |
| 123-124 | Installation of block I equipment |
| 124-126 | Washing, blowdown and testing |
| 127-128 | Installation of block II equipment |
| 128-129 | Washing, blowdown, testing |
| | **Starting up boiler room** |
| 131-132 | Construction operations |
| 132-133 | Installation of equipment |
| 133-134 | Adjustment |
| | **Vent pipe** |
| 136-137 | Construction operations |
| 137-138 | Installation of dosimetric monitoring and lighting |
| | **Outdoor distribution station** |
| 140-141 | Construction operations |
| 141-142 | Installation of block I equipment |
| 142-143 | End of construction operations |
| 144-145 | Installation of block II equipment |
| 145-146 | End of construction operations |
| | **Outdoor transformer station** |
| 148-149 | Construction operations of block I |
| 150-151 | Construction operations of block II |
| 153-154 | Equipment installation of block I |
| 155-156 | Equipment installation of block II |
| | **Associated auxiliary facility** |
| 158-159 | Construction operations |
| 159-160 | Installation of equipment |
| 160-161 | Finishing operations |
| | **Sanitation and general services building** |
| 163-164 | Construction operations |
| 164-165 | Installation operations |
| | **Engineering and general services building** |
| 166-167 | Construction operations |
| 168-169 | Installation operations |

| | | |
|---|---|---|
| | Administrative building | |
| 170-171 | | Construction operations |
| | Hydraulic engineering structures | |
| 174-175 | | Construction of circulation lines for the power plant complex of block II |
| 175-176 | | Erection of structures and buildings of block II |
| 177-178 | | Construction of circulation lines in the station zone of block I |
| 178-179 | | Erection of structures and buildings of block I |
| | Other facilities and operations | |
| 0-180 | | Erection of temporary buildings and structures |
| 180-181 | | Construction of block I facilities |
| 181-182 | | Construction of block II facilities |

Appendix 6-5. PERT chart of the Construction of Nuclear Power Plants with RBMK-1000 Reactor



Key (Appendix 6-5):
a. structures
b. ... year
c. exploitation of territory
d. transport and communication projects
e. engineering works
f. temporary structures
g. block A
h. block V
i. block G
j. block B
k. Block Ye
l. main facility
m. auxiliary structures
n. process water supply
o. cooling pond
p. power plant complex
q. cost of construction and installation operations for power unit I, millions of rubles

| Chart positions | Types of operations |
|---|---|
| | General site operations |
| 0-1 | Preparation of construction site |
| 0-2 | Construction of roadways and railways |
| 0-3-4 | Construction of water supply and sewage |
| 0-7 | Construction of temporary building and structures |
| | Construction of block A |
| 8-9 | Earthwork |
| 9-11 | Construction of foundation slab |
| 12-14 | Erection of block to the 38.2 meter mark |
| 14-15 | Installation of metal structural elements for the reactor division to the 56.2 meter mark |
| 17-19 | Installation of auxiliary equipment |
| 20 | Delivery of system E |
| 21-22 | Consolidation assembly of system E |
| 23-26 | Construction of winter shelters for the consolidation assembly of the reactor |
| 25 | Delivery of the OR system |
| 25-29-46 | Consolidation assembly of the OR system |
| 30 | Delivery of the S system |
| 30-32 | Consolidation assembly of S system |
| 32-34 | Break-in of S system |
| 36 | Delivery of L system |
| 37 | Consolidation assembly of L system |
| 38 | Delivery of KZh system |
| 38-39 | Consolidation assembly of KZh system |
| 40-41 | Delivery of Ye system |
| 42-44 | Consolidation assembly of Ye system |
| 44-45 | Welding in the loops |
| 46-48-158 | Installation of equipment No 1 in the block shaft |
| 49 | Delivery of system G |
| 50-51 | Consolidation assembly of system G |
| 51-52 | Installation of system G |

Construction of block V

| | |
|---|---|
| 53-54 | Earth work |
| 54-56 | Construction of foundation slab |
| 57-60 | Erection of block to the 8.2 meter mark |
| 60-61 | Erection of block to the 17.2 meter mark |
| 61-62 | Erection of block to the 32.0 meter mark |
| 63-66 | Installation of process equipment |
| 67-68 | Finishing off the openings |

Construction of block G

| | |
|---|---|
| 69-71 | Earth work |
| 72-74 | Concrete preparation and horizontal hydraulic insulation structure |
| 75-77 | Erection of foundations along the A, G, V and B axes |
| 75-80 | Installation of the structural elements of the machine room and deaerator stack |
| 80-87 | Erection of inside facilities of the stack |
| 81-84 | Erection of the foundation and boxes of turbogenerator No 2 |
| 83-86 | Erection of a foundation and boxes of turbogenerator No 1 |
| 87-88 | Finishing off the openings |
| 89-97 | Installation of turbogenerator No 1 |
| 90-92 | Installation of machine room crane No 1 |
| 92-94 | Installation of machine room crane No 2 |
| 93-98 | Installation of process equipment |
| 94-95 | Installation of turbogenerator No 2 |
| 95-98 | Covering of boxes |
| 98-99 | Testing the turbogenerators Nos 1 and 2 |
| 100-101 | Erection of foundations with respect to A axis and 68 and construction of the foundation slab |
| 101-103 | Installation of the structural elements of the machine room and the deaerator stack |
| 103-104 | Erection of inside facilities of the stack |
| 105-106 | Erection of foundation and boxes of turbogenerator No 3 |

Construction of block B

| | |
|---|---|
| 107-108 | Earthwork |
| 108-112 | Construction of foundation slab |
| 111-114 | Erection of block to the 15.0 meter mark |
| 114-115 | Erection of block to the 38.2 meter mark |
| 116-117 | Delivery of the equipment systems No 2 |
| 116-119 | Consolidation assembly of the systems of equipment No 2 |

Construction of block Ye

| | |
|---|---|
| 120-163 | Construction of block Ye |

Construction of industrial site structures

| | |
|---|---|
| 121-122 | Construction of reserve boiler room |
| 123-124 | Construction of vent pipe |
| 125-129 | Construction of storage for solid and liquid waste |

| | |
|---|---|
| 126-127 | Installation of equipment |
| 130-134 | Construction of the 330 and 110 kv outdoor distribution stations |
| 131-135 | Installation operations |
| 135-137 | Construction of the associated auxiliary facilities |
| 136-138 | Installation of equipment |
| 139-140 | Construction of auxiliary structures |
| | Construction of the process water supply facilities |
| 141-145 | Filling the dam, reinforcing and construction of drainage |
| 142-143-146 | Excavation, fill and reinforcing of ship channel |
| 147-148 | Construction of makeup station and other structures |
| 149-151-156 | Reinforcing of supply and discharge canal banks |
| 152-153 | Construction of pumping stations Nos 1 and 2 and installation of No 2 station equipment |
| 154-155 | Construction of water intake structures, head-pond and other structures; installation of equipment of structure No 2 |
| 156-157 | Filling of the pond |
| | Startup and adjustment operations |
| 158-159 | Hydraulic testing, flushing |
| 160-163 | Physical startup, power production startup |

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